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Issues in Ecology
Published by the Ecological Society of America
Number 10, Winter 2003

Sustaining Healthy Freshwater Ecosystems

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SUMMARY

Fresh water is vital to human life and economic well-being, and societies extract vast quantities of water from rivers, lakes, wetlands, and underground aquifers to supply the requirements of cities, farms, and industries. Our need for fresh water has long caused us to overlook equally vital benefits of water that remains in stream to sustain healthy aquatic ecosystems. There is growing recognition, however, that functionally intact and biologically complex freshwater ecosystems provide many economically valuable commodities and services to society. These services include flood control, transportation, recreation, purification of human and industrial wastes, habitat for plants and animals, and production of fish and other foods and marketable goods. Over the long term, intact ecosystems are more likely to retain the adaptive capacity to sustain production of these goods and services in the face of future environmental disruptions such as climate change. These ecosystem benefits are costly and often impossible to replace when aquatic systems are degraded. For this reason, deliberations about water allocation should always include provisions for maintaining the integrity of freshwater ecosystems.

Scientific evidence indicates that aquatic ecosystems can be protected or restored by recognizing the following:

- Rivers, lakes, wetlands, and their connecting ground waters are literally the “sinks” into which landscapes drain. Far from being isolated bodies or conduits, freshwater ecosystems are tightly linked to the watersheds or catchments of which each is a part, and they are greatly influenced by human uses or modifications of land as well as water. The stream network itself is important to the continuum of river processes.
- Dynamic patterns of flow that are maintained within the natural range of variation will promote the integrity and sustainability of freshwater aquatic systems.
- Aquatic ecosystems additionally require that sediments and shorelines, heat and light properties, chemical and nutrient inputs, and plant and animal populations fluctuate within natural ranges, neither experiencing excessive swings beyond their natural ranges nor being held at constant levels.

Failure to provide for these natural requirements results in loss of species and ecosystem services in wetlands, rivers, and lakes. Scientifically defining requirements for protecting or restoring aquatic ecosystems, however, is only a first step. New policy and management approaches will also be required. Current piecemeal and consumption-oriented approaches to water policy cannot solve the problems confronting our increasingly degraded freshwater ecosystems. To begin to redress how water is viewed and managed in the United States, we recommend:

1) Framing national, regional, and local water management policies to explicitly incorporate freshwater ecosystem needs.
2) Defining water resources to include watersheds, so that fresh waters are viewed within a landscape or ecosystem context instead of by political jurisdiction or in geographic isolation.
3) Increasing communication and education across disciplines, especially among engineers, hydrologists, economists, and ecologists, to facilitate an integrated view of freshwater resources.
4) Increasing restoration efforts using well-grounded ecological principles as guidelines.
5) Maintaining and protecting remaining freshwater ecosystems that have high integrity.
6) And recognizing human society’s dependence on naturally functioning ecosystems.

Cover—(1) Rio Grande at Bandelier National Monument, New Mexico. Photo courtesy Jim Thibault, University of New Mexico Biology Department; (2) Rio Grande near Bernalillo, New Mexico. Photo courtesy Anders Molles, son of Manuel C. Molles, Jr., University of New Mexico Biology Department; (3) Dry Rio Grande at Bosque del Apache National Wildlife Refuge, July 17, 2002. Photo courtesy Jennifer Schuetz, University of New Mexico Biology Department.

Sustaining Healthy Freshwater Ecosystems

by Jill S. Baron, N. LeRoy Poff, Paul L. Angermeier, Clifford N. Dahm, Peter H. Gleick, Nelson G. Hairston, Jr., Robert B. Jackson, Carol A. Johnston, Brian D. Richter, Alan D. Steinman

INTRODUCTION

Fresh water is vital to human life and economic well-being, and societies draw heavily on rivers, lakes, wetlands, and underground aquifers to supply water for drinking, irrigating crops, and running industrial processes. The benefits of these extractive uses of fresh water have traditionally overshadowed the equally vital benefits of water that remains in stream to sustain healthy aquatic ecosystems. There is growing recognition that functionally intact and biologically complex freshwater ecosystems provide many economically valuable commodities and services to society (Figure 1). The services supplied by freshwater ecosystems include flood control, transportation, recreation, purification of human and industrial wastes, habitat for plants and animals, and production of fish and other foods and marketable goods. These human benefits are what ecologists call ecological services, defined as "the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life." Over the long term, healthy freshwater ecosystems are likely to retain the adaptive capacity to sustain production of these ecological services in the face of future environmental disruptions such as climate change.

Figure 1—Freshwater ecosystems provide economically valuable commodities and services to humans (drinking water, irrigation, transportation, recreation, etc.), as well as habitat for plants and animals.

Ecological services are costly and often impossible to replace when aquatic ecosystems are degraded. Yet today, aquatic ecosystems are being severely altered or destroyed at a greater rate than at any other time in human history, and far faster than they are being restored. Debates involving sustainable allocation of water resources should recognize that maintenance of freshwater ecosystem integrity is a legitimate goal that must be considered among the competing demands for fresh water. Coherent policies are required that more equitably allocate water resources between natural ecosystem functioning and society's extractive needs.

Current water management policies in the United States are clearly unable to meet this goal. Literally dozens of different government entities have a say in what wastes can be discharged into water or how water is used and redistributed, and the goals of one agency are often at cross-purposes with those of others. U. S. laws and regulations concerning water are implemented in a management context that focuses primarily on maintaining the lowest acceptable water quality and minimal flows, and protecting single species rather than aquatic communities. A fundamental change in water management policies is needed, one that embraces a much broader view of the dynamic nature of freshwater resources and the short- and long-term benefits they provide.

Our current educational practices are as inadequate as management policies to the challenge of sustainable water resource management. Hydrologists, engineers, and water managers, the people who design and manage the nation's water resource systems, are rarely taught about the ecological consequences of management policies. Likewise, ecologists are rarely trained to consider the critical role of water in human society or to understand the institutions that manage water. Economists, developers, and politicians seldom project far enough into the future to fully account for the potential ecological costs of short-term plans. Few Americans are aware of the infrastructure that brings them pure tap water or carries their wastes away, and fewer still understand the ecological tradeoffs that are made to allow these conveniences.

Although the requirements of healthy freshwater ecosystems are often at odds with human activity, this conflict need not be inevitable. The challenge is to determine how society can extract the water resources it needs while protecting the important natural complexity and adaptive capacity of freshwater ecosystems. Current scientific understanding makes it possible to outline here in general terms the requirements for adequate quantity, quality, and timing of water flow to sustain the functioning of freshwater ecosystems. A critical next step will be communication of these requirements to a broader community. The American public, when given information about management alternatives, supports ecologically based management approaches, particularly toward fresh water.

Several previous studies that have addressed the overall condition of freshwater resources have recognized that

- water movement through the biosphere is highly altered by human activities;
- water is intensively used by humans;
- poor water quality is pervasive;

Table 1— Changes in hydrologic flow, water quality, wetland area, and species viability in U.S. rivers, lakes, and wetlands since Euro-American settlement.

U. S. Freshwater Resources	Pre-settlement Condition	Current Conditions	Source
Undammed rivers (in 48 contiguous states)	5.1 million km	4.7 million km	Echeverria et al. 1989
Free-flowing rivers that qualify for wild and scenic status (in 48 contiguous states)	5.1 million km	0.0001 million km	US DOI 1982
Number of dams >2m	0	75,000	CEQ 1995
Volume of water diverted from surface waters	0	10 million $m^3 day^{-1}$(1985)	Solley et al. 1998
Total daily U. S. water use	Unknown	1.5 million $m^3 day^{-1}$(1995)	Solley et al. 1998
Sediment inputs to reservoirs	not applicable	1,200 million m^3/year	Stallard 1998
River water quality*(1.1 million km surveyed)	Unimpaired	402,000 km impaired*	EPA 1998
Lake water quality*(6.8 million ha surveyed)	Unimpaired	2.7 million ha impaired*	EPA 1998
Wetland acreage (in 48 contiguous states)	87 million ha	35 million ha	van der Leeden et al. 1990
Number of native freshwater fish species	822 species	202 imperiled or extinct	Stein and Flack 1997
Number of native freshwater mussel species	305 species	157 imperiled or extinct	Stein and Flack 1997
Number of native crayfish species	330 species	111 imperiled or extinct	Stein and Flack 1997
Number of native amphibian species	242 species	64 imperiled or extinct	Stein and Flack 1997

*Only 19% (1,116,500 km) of total river km in U. S. were surveyed out of a total of 5,792,400 km. Only 40% (6.8 million ha) of total lake area (16.9 million ha) were surveyed.

- and freshwater plant and animal species are at greater risk of extinction from human activities compared with all other species.

These and other analyses indicate that freshwater ecosystems are under stress and at risk (Table 1).

Clearly, new management approaches are needed. In this paper we describe the requirements for water of sufficient quality, amount, timing, and flow variability in freshwater ecosystems to maintain the natural dynamics that produce ecosystem goods and services. We suggest steps to be taken toward restoration and conclude with recommendations for protecting and maintaining freshwater ecosystems.

REQUIREMENTS FOR FRESHWATER ECOSYSTEM INTEGRITY

Freshwater ecosystems differ greatly from one another depending on type, location, and climate, but they nevertheless share important features. For one, lakes, wetlands, rivers, and their connected ground waters share a common need for water within a certain range of quantity and quality. In addition, because freshwater ecosystems are dynamic, all require a range of natural variation or disturbance to maintain viability or resilience. Water flows that vary both season to season and year to year, for example, are needed to support plant and animal communities and maintain natural habitat dynamics that support production and survival of species. Variability in the timing and rate of water flow strongly influence the sizes of native plant and animal populations and their age structures, the presence of rare or highly specialized species, the interactions of species with each other and with their environments, and many ecosystem processes. Periodic and episodic water flow patterns also influence water quality, physical habitat conditions and connections, and energy sources in aquatic ecosystems. Freshwater ecosystems, therefore, have evolved to the rhythms of natural hydrologic variability.

The structure and functioning of freshwater ecosystems are also tightly linked to the watersheds, or catchments, of which they are a part. Water flowing through the landscape on its way to the sea moves in three dimensions, linking upstream to downstream, stream channels to floodplains and riparian wetlands, and surface waters to ground water. Materials generated across the landscape ultimately make their way into rivers, lakes, and other freshwater ecosystems. Thus these systems are greatly influenced by what happens on the land, including human activities.

We have identified five dynamic environmental factors that regulate much of the structure and functioning of any aquatic ecosystem, although their relative importance varies among aquatic ecosystem types (Figure 2). The interaction

of these drivers in space and time defines the dynamic nature of freshwater ecosystems:

1. The *flow pattern* defines the rates and pathways by which rainfall and snowmelt enter and circulate within river channels, lakes, wetlands, and connecting ground waters, and also determines how long water is stored in these ecosystems.

2. *Sediment and organic matter inputs* provide raw materials that create physical habitat structure, refugia, substrates, and spawning grounds and supply and store nutrients that sustain aquatic plants and animals.

3. *Temperature and light characteristics* regulate the metabolic processes, activity levels, and productivity of aquatic organisms.

4. *Chemical and nutrient conditions* regulate pH, plant and animal productivity, and water quality.

5. The *plant and animal assemblage* influences ecosystem process rates and community structure.

In naturally functioning freshwater ecosystems, all five of these factors vary within defined ranges throughout the year, tracking seasonal changes in climate and day length. Species have evolved and ecosystems have adjusted to accommodate these annual cycles. They have also developed strategies for surviving – and often requiring — periodic hydrologic extremes caused by floods and droughts that exceed the normal annual highs or lows in flows, temperature, and other factors.

Focusing on one factor at a time will not yield a true picture of ecosystem functioning. Evaluating freshwater ecosystem integrity requires that all five of these dynamic environmental factors be integrated and considered jointly.

Flow Patterns

An evaluation of the characteristics required for healthy functioning can begin with a description of the natural or historical flow patterns for streams, rivers, wetlands and lakes. Certain aspects of these patterns are critical for regulating biological productivity (that is, the growth of algae or phytoplankton that form the base of aquatic food webs) and biological diversity, particularly for rivers. These aspects include base flow, annual or frequent floods, rare and extreme flood events, seasonality of flows, and annual variability (BOX 1). Such factors are also relevant for evaluating the integrity of lakes and wetlands because flow patterns and hydroperiod (that is, seasonal fluctuations in water levels) influence water circulation patterns and renewal rates, as well as types and abundances of aquatic vegetation such as reeds, grasses, and flowering plants. Furthermore, the characteristic flow pattern of a lake, wetland, or stream critically influences algal productivity and is an important factor to be considered when determining acceptable levels of nutrient (nitrogen and phosphorus) runoff from the surrounding landscape.

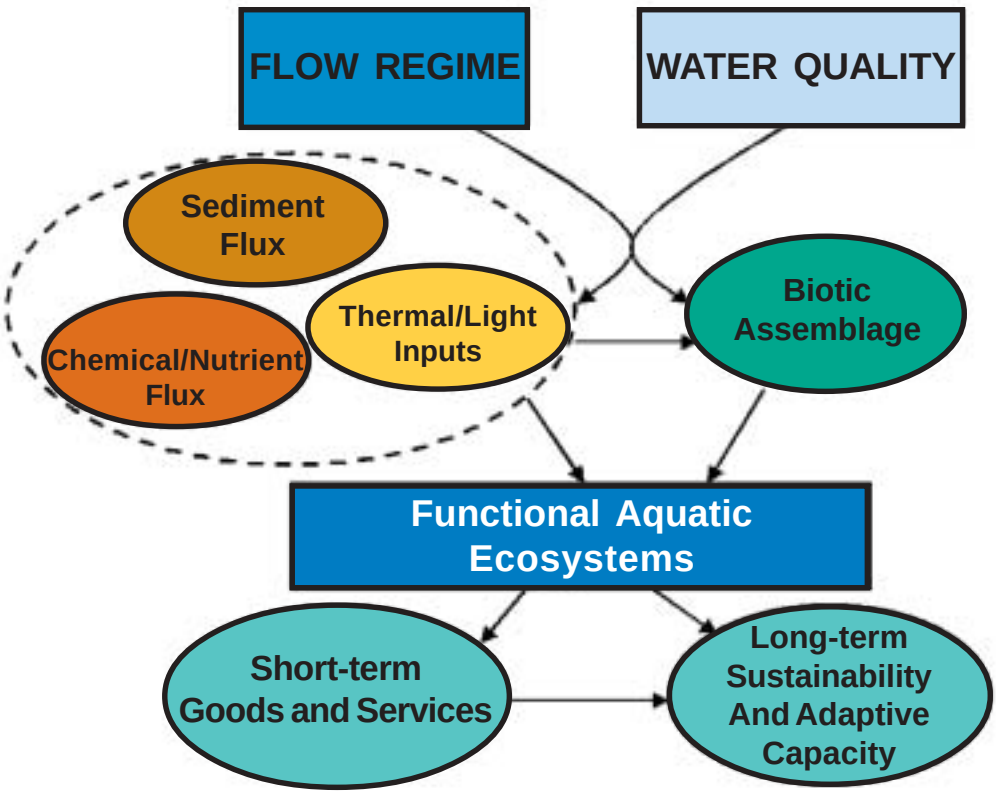

Figure 2— Conceptual model of major forces that influence freshwater ecosystems.

BOX 1— DEFINING FLOW CONDITIONS FOR RIVERS AND STREAMS

Base flow conditions characterize periods of low flow between storms. They define the minimum quantity of water in the channel, which directly influences habitat availability for aquatic organisms as well as the depth to saturated soil for riparian species. The magnitude and duration of base flow varies greatly among different rivers, reflecting differences in climate, geology, and vegetation in a watershed.

Frequent (that is, two-year return interval) floods reset the system by flushing fine materials from the streambed, thus promoting higher production during base flow periods. High flows may also facilitate dispersal of organisms both up- and downstream. In many cases moderately high flows inundate adjacent floodplains and maintain riparian vegetation dynamics.

Rare or extreme events such as 50- or 100-year floods represent important reformative events for river systems. They transport large amounts of sediment, often transferring it from the main channel to floodplains. Habitat diversity within the river is increased as channels are scoured and reformed and successional dynamics in riparian communities and floodplain wetlands are reset. Large flows can also remove species that are poorly adapted to dynamic river environments such as upland tree species or non-native fish species. The success of non-native invaders is often minimized by natural high flows, and the restriction of major floods by reservoirs plays an important role in the establishment and proliferation of exotic species in many river systems.

Seasonal timing of flows, especially high flows, is critical for maintaining many native species whose reproductive strategies are tied to such flows. For example, some fish use high flows to initiate spawning runs. Along western rivers, cottonwood trees release seeds during peak snowmelt to maximize the opportunity for seedling establishment on floodplains. Changing the seasonal timing of flows has severe negative consequences for aquatic and riparian communities.

Annual variation in flow is an important factor influencing river systems. For example, year-to-year variation in runoff volume can maintain high species diversity. Similarly, ecosystem productivity and foodweb structure can fluctuate in response to this year-to-year variation. This variation also ensures that various species benefit in different years, thus promoting high biological diversity.

Human alterations of river flow have seldom taken into account the ecological consequences. "Many rivers now resemble elaborate plumbing works, with the timing and amount of flow completely controlled, like water from a faucet, so as to maximize the rivers' benefits for humans," wrote water policy expert Sandra L. Postel. "But while modern engineering has been remarkably successful at getting water to people and farms when and where they need it, it has failed to protect the fundamental ecological function of rivers and aquatic systems."

Rivers in the U.S. West are prime examples of how human manipulation of water flows can lead to multiple damages to riverbank and floodplain processes and communities. Damming rivers and dampening natural variations in flow rates by maintaining minimum flows year round have contributed to widespread loss of native fish species and regeneration failure of native cottonwood trees, which used to support diverse riparian communities (BOX 2).

Sediment and Organic Matter Inputs

In river systems, the movement of sediments and influxes of organic matter are important components of habitat structure and dynamics. Natural organic matter inputs include seasonal runoff and debris such as leaves and decaying plant material from land-based communities in the watershed. Especially in smaller rivers and streams, the organic matter that arrives from the land is a particularly important source of energy and nutrients, and tree trunks and other woody materials that fall into the water provide important substrates and habitats for aquatic organisms. Natural sediment movements are those that accompany natural variations in water flows. In lakes and wetlands, all but the finest inflowing sediment falls permanently to the bottom, so that over time these systems fill. The invertebrates, algae, bryophytes,

Figure 3—Livestock use of streams can have impacts on the amount of sediment and nutrients inputs. Photo courtesy the U.S. Geological Survey, South Platte National Water Quality Assessment Program (NAWQA).

vascular plants, and bacteria that populate the bottoms of freshwater systems are highly adapted to the specific sediment and organic matter conditions of their environment, as are many fish species, and do not persist if changes in the type, size, or frequency of sediment inputs occur. The fate of these organisms is critical to sustaining freshwater ecosystems since they are responsible for much of the work of water purification, decomposition, and nutrient cycling.

Humans have severely altered the natural rates of sediment and organic matter supply to aquatic systems, increasing some inputs while decreasing others (Figure 3). Poor agricultural, logging, or construction practices, for example, promote high rates of soil erosion. In many areas small streams or wetlands have even been completely eliminated through filling, paving, or re-routing into artificial channels. The U.S. Environmental Protection Agency (EPA) reports that in one quarter of all lakes with sub-standard water quality, the cause of impairment is silt entering from agricultural, urban, construction, and other non-point (widely dispersed) sources. Dams alter sediment flows both for the reservoirs behind them and the streams below, silting up the former while starving the latter. By one estimate, another 1.2 billion cubic meters of sediment builds up each year in U. S. reservoirs (Table 1). This sediment capture in turn cuts off normal sand, silt, and gravel supplies to downstream reaches, causing streambed erosion that both degrades in-channel habitat and isolates floodplain and riparian wetlands from the channel during rejuvenating high flows. Channel straightening, overgrazing of river and stream banks, and clearing of streamside vegetation reduce organic matter inputs and often increase erosion.

Figure 4—Eutrophication from irrigation return flows. Photo courtesy the U.S. Geological Survey, South Platte National Water Quality Assessment Program (NAWQA).

Temperature and Light

The light and heat properties of a body of water are influenced by climate and topography as well as by the characteristics of the water body itself: its chemical composition, suspended sediments, and algal productivity. Water temperature directly regulates oxygen concentrations, the metabolic rate of aquatic organisms, and associated life processes such as growth, maturation, and reproduction. The temperature cycle greatly influences the fitness of aquatic plants and animals and, by extension, where species are distributed in the system and how the living community in a body of water varies from season to season. In lakes particularly, the absorption of solar energy and its dissipation as heat are critical to development of temperature gradients between the surface and deeper water layers and also to water circulation patterns. Circulation patterns and temperature gradients in turn influence nutrient cycling, distribution of dissolved oxygen, and both the distribution and behavior of organisms, including game fishes. Water temperature can change dramatically downstream of dams (BOX 2). In Utah's Green River, mean monthly water temperatures ranged between 2 degrees Celsius (C) in winter and 18 degrees C in summer before completion of the Flaming Gorge Dam in 1962. After dam closure, the annual range of mean monthly water temperatures below the dam was greatly narrowed, to between 4 C and 9 C. As a result, species richness declined and 18 genera (that is, groups of related species) of insects were lost; other species, notably freshwater shrimp, came to dominate the ranks of invertebrate animals. Aquatic insects have not recovered despite 20 years of partial temperature restoration achieved by releasing water from warmer reservoir water layers. Water temperature also dropped in the Colorado River after closure of the Glen Canyon Dam in 1963, and there was a dramatic increase in water clarity. Water clarity now routinely allows visibility to greater than 7 meters, whereas prior to dam closure, the water column was opaque with suspended sediments. The colder, clearer waters have allowed a non-native trout population to flourish, at the top of an unusual food web more commonly found much further north.

Nutrient and Chemical Conditions

Natural nutrient and chemical conditions are those that reflect local climate, bedrock, soil, vegetation type, and topography. Natural water conditions can range from clear, nutrient-poor rivers and lakes on crystalline bedrock to much more chemically enriched and algae-producing freshwaters in catchments with organic matter-rich soils or limestone bedrock. This natural regional diversity in watershed characteristics, in turn, sustains high biodiversity.

A condition known as cultural eutrophication occurs when additional nutrients, chiefly nitrogen and phosphorus, from human activities enter freshwater ecosystems (Figure 4). The result is a decrease in biodiversity, although productivity of certain algal species can increase well beyond original levels. Midwestern and Eastern lakes such as Lakes Michigan, Huron, Erie, and

Ontario demonstrate the consequences of excess inputs of nutrients and toxic contaminants, as well as non-native species introductions and over-fishing (BOX 3). Onondaga Lake, New York, which was polluted with salt brine effluent from a soda ash industry, likewise responded with marked changes in the plankton and fish communities, including invasions by non-native fish species. Among U.S. lakes identified by the EPA as impaired in 1996, excess nutrients contributed to more than half of the water quality problems. More than half of agricultural and urban streams sampled by the U. S. Geological Survey were found to have pesticide concentrations that exceed guidelines for the protection of aquatic life.

Plant and Animal Assemblages

The community of species that lives in any given aquatic ecosystem reflects both the pool of species available in the region and the abilities of individual species to colonize and survive in that water body. The suitability of a freshwater ecosystem for any particular species is dictated by the environmental conditions – that is, water flow, sediment, temperature, light, and nutrient patterns — and the presence of, and interactions among, other species in the system. Thus, both the habitat and the biotic community provide controls and feedbacks that maintain a diverse range of species. The high degree of natural variation in environmental conditions in fresh waters across the United States promotes high biological diversity. In fact, North American freshwater habitats are virtually unrivaled in diversity of fish, mussel, crayfish, amphibian, and aquatic reptile species compared with anywhere else in the world. The biota, in turn, are involved in shaping the critical ecological processes of primary production, decomposition, and nutrient cycling. Within a body of water, species often perform overlapping, apparently redundant roles in these processes, a factor that helps provide local ecosystems with a greater capacity to adapt to future environmental variation. High apparent redundancy (that is, species richness or biodiversity) affords a kind of insurance that ecological functions will continue during environmental stress. Critical to this is connectivity among water bodies, which allows species to move to more suitable habitat as environmental conditions change.

Figure 5—Freshwater ecosystems provide habitats to plants and animals. Human activities and water use place many of these freshwater species at risk of extinction. Photo courtesy the U.S. Geological Survey, South Platte National Water Quality Assessment Program (NAWQA).

Human activities that alter freshwater environmental conditions can greatly change both the identity of the species in the community and the functioning of the ecosystem (Figure 5). Excessive stress or simplification of natural complexity has the potential to push functionally intact freshwater ecosystems beyond the bounds of resilience or sustainability, threatening their ability to provide important goods and services on both short and long time scales. Further, introduction of non-native species that can thrive under the existing or altered range of environmental variation can contribute to the extinction of native species, severely modify food webs, and alter ecological processes such as nutrient cycling. Exotic species are often successful in modified systems, where they can be difficult to eradicate.

TOOLS AVAILABLE FOR RESTORATION

Despite widespread degradation of freshwater ecosystems, management techniques are available that can restore these systems to a more natural and sustainable state and prevent continued loss of biodiversity, ecosystem functioning, and ecological integrity. One technique, for example, involves restoring some of the natural variations in stream flow, based on the understanding that river systems are naturally dynamic. New statistical approaches to setting management targets for streamflow variability over time have been applied to or proposed for several rivers, including the Flathead River in Montana, the Roanoke River in North Carolina, and the vast Colorado River system in the West. These variable streamflow techniques seek a balance between water delivery needs for power generation or irrigation, and in-stream ecological needs for flow variability that displays a certain timing, frequency, duration, and rate of change characteristic of the natural system (Figure 6). Restoring this flow variability helps to reconnect dynamic riparian and groundwater systems with surface flows, enabling water to move more naturally through all the spatial dimensions that are essential to fully functional ecosystems.

Other restoration efforts target pollution, both from point sources such as effluent from industrial or sewage pipes and nonpoint sources such as fertilizer runoff from urban lawns and rural croplands. Point sources of water pollution are readily identified, and many have been controlled, thanks in large part to the federal Clean Water Act and Safe Drinking Water Act. Nonpoint sources of nutrients and toxins now supply the majority of pollutants to freshwater ecosystems. In some situations, best management practices have succeeded in reducing runoff of agricultural pollutants. These practices include erosion control and moderate applications of fertilizers, pesticides and herbicides. Best management practices require willing farmers, however, and willingness is often a response either to economic incentives or to stringent

BOX 2 — THE COLORADO RIVER

The Colorado River is one of the most highly regulated and heavily used river systems in the world. Two principal reservoirs, Lakes Powell and Mead, along with 12 other large reservoirs store and release water according to complicated equations designed to maximize both hydroelectric generation and water supplies for agricultural, domestic, and industrial use in seven states across the Western United States and Mexico. More than 30 million people depend on Colorado River water. The original Colorado River Compact of 1928 allocated all water for societal use. (Actually it over-allocated because typical water volumes were overestimated while year-to-year variability was ignored.)

Physical changes to the river below the dams have been profound. Flow in the Colorado River is snowmelt driven, and pre-dam flow patterns were dominated by large discharges from April through July, followed by low flows in late summer and fall. The river carried tremendous amounts of sediment from the highly erodible Colorado Plateau, and river temperatures were seasonally warm. Today, river flow is nearly decoupled from natural snowmelt, and peak discharges can occur in any month, often November to January. Daily changes in water releases as great as 566 cubic meters per second occur regularly for hydropower generation. Alluvial sediment, which once played a vital role in creating in-channel habitat, is now trapped behind the dams, and the waters below are clear and sediment-starved. Also, because water is released from the bottom waters of most reservoirs, water temperatures for hundreds of kilometers below the dams are very cold throughout the summer and relatively warm during the winter, a reversal of the natural seasonal cycle. (An exception is Flaming Gorge Reservoir on the Green River in the upper Colorado basin, where water is released from multiple reservoir layers.)

Ecological responses to the dams have been equally profound. The clear, cold tail waters below the dams, in conjunction with widespread introduction of non-native species, have promoted food webs that are alien to the Colorado River. Prior to regulation, the organic matter that fueled the river food web primarily originated on land and was carried into the river during large runoff events. Now, organic matter is supplied largely by luxuriant mats of algae that grow on the bottom of the river. The algae are consumed by insects and other invertebrates that historically occurred only in the much colder tributaries of the Colorado; these insects and invertebrates are in turn eaten by non-native rainbow and brown trout. Below the Glen Canyon Dam that holds Lake Powell, only four out of eight indigenous fish species remain, along with 22 non-native fishes, many of which either compete with or directly feed on the endangered native fish. Native cottonwood trees and the animal community they support are declining because the trees are unable to take root under variable flows. Also, upstream reservoirs that reduce the magnitude of annual floods prevent the establishment of cottonwoods higher on the riverbanks. Other shrubs and trees that are more tolerant of these modified conditions have grown profusely, including non-natives such as tamarisk.

The effects of 14 major dams and hundreds of water diversions have been felt all the way to the river mouth. Since completion of the Glen Canyon Dam in 1963, measurable flows from the Colorado River into the Sea of Cortez have occurred only infrequently. The wetland area at the mouth of the river has decreased from a historical average of 250,000 hectares to 5,800 to 63,000 hectares (depending on the year). In the Sea of Cortez, the lack of freshwater inflows has contributed to the endangerment of a large number of species, and the loss of algal productivity has caused the abundance of bivalve mollusk populations to drop 94 percent from 1950 values.

To reduce the impact of dam operations on the river's ecological resources, Congress passed the Grand Canyon Protection Act of 1992. A large group of Colorado River stakeholders now work with a Department of Interior sponsored Grand Canyon Monitoring and Research Center to attempt through adaptive management to protect and restore riparian areas and native fishes, several of which are threatened or endangered. In 1996, after nearly 15 years of study, a large experimental flood was generated to help scientists and managers investigate the effects of high flows on sediment transport and biological, cultural, and socioeconomic resources. Another set of experimental floods is planned, along with aggressive efforts to reduce non-native trout populations. There is also discussion of installing a thermal control device on Glen Canyon Dam to raise water temperatures below it. Partial restoration of historic temperatures below Flaming Gorge Dam on the Green River, however, have not improved conditions for aquatic insects directly below the dam. More than 20 years later, the number of species is as low or lower than before the restoration efforts began. Further downstream, the number of insect taxa did increase, but only because warmer summer temperatures occurred in combination with periodic floods and sediment inputs from a tributary.

Is it possible to manage a river as highly regulated as the Colorado in ways that protect and improve environmental conditions for the native biota? Only time will tell, but an important first step is recognizing that key processes and conditions must be allowed to fluctuate within a range of natural variability.

Photo credits, clockwise from top center: Green River, 22 May 1871: John Wesley Powell Photographs / # 17234, Grand Canyon National Park Museum Collection; Loch Vale Watershed, CO: J. Baron; Colorado River: K. Henry; Grand Canyon ca. 1872, John Wesley Powell Photographs / # 17248, Grand Canyon National Park Museum Collection; Colorado River delta: Jennifer Pitt, Environmental Defense; Lake Mead: National Park Service; Hoover Dam, 2002: P. Nagler; Glen Canyon Dam: Bureau of Reclamation, Upper Colorado Region.

regulations. To help in determining best management practices, the EPA has recently published guidelines for establishing acceptable nutrient runoff criteria for different regions of the United States, recognizing the inherent natural variability in local and regional availability of nutrients. The guidelines are based on Total Maximum Daily Load (TMDL), a calculation of the maximum amount of a pollutant that a water body can receive and still meet water quality standards. To allow for natural variation, water quality standards for a pollutant are established within each ecoregion based on comparison with relatively unpolluted waters or – if few or no unpolluted waters remain in a region — on waters with the lowest pollution levels (Figure 7). Once a standard is set, management practices can be enacted to reduce inputs of unwanted pollutants.

Another large source of nonpoint pollution is atmospheric deposition of nitrogen and other contaminants that fall as acid rain or dry pollutants. These could be

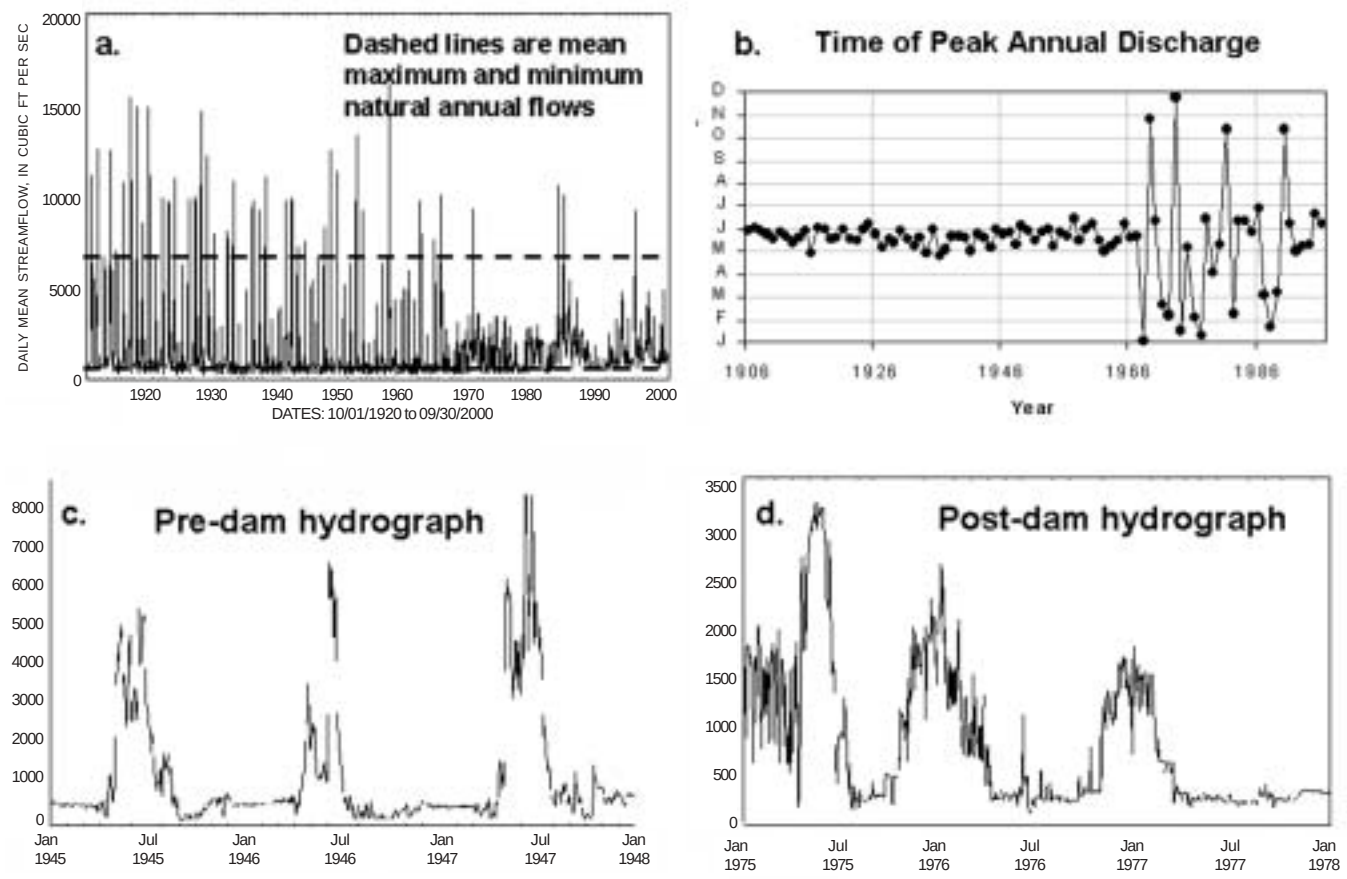

Figure 6 — Hydrologic characteristics for the Gunnison River, Colorado (site #09128000; USGS Water Resources Data of USA: http://water.usgs.gov/nwis). a) Daily mean streamflow (cubic feet per second) for the period 1906-1996. Dashed lines show mean maximum and minimum pre-dam construction annual flows; b) Time of year for peak annual discharge in the Gunnison River, showing April through June snowmelt-driven discharge until dam closure in 1968, when discharge maxima switched to the period October to March, reflecting water releases for hydroelectric power generation; c) Daily hydrograph for pre-dam period 1945-1957; d) Daily hydrograph for post-dam period 1975-1977. One method of restoring a more natural flow pattern calls for establishing a new range for maximum and minimum flows and timing of maximum flows that falls within the range of natural variation.

reduced through more stringent controls on emissions of sulfur, nitrogen, metals, and organic toxins, and through development and application of more efficient transportation and energy production technologies.

CHALLENGES AHEAD

The problems confronting freshwater ecosystems will be intractable if they continue to be approached piecemeal. Several government programs, such as the EPA Clean Lakes Program, the Wetlands Restoration Act, and even the Endangered Species Act, mandate actions to prevent specific aspects of ecosystem degradation. But these programs are narrow in focus, effectively addressing symptoms rather than root causes of aquatic ecosystem decline. Control of pollution is necessary, for instance, but insufficient for maintaining a native species community if adequate water flows are not available at the right time, if the channel has been severely degraded, or if invasive species have been allowed to take hold. The needs of aquatic ecosystems and the needs of society for water supplies must be addressed collectively if freshwater ecological integrity is to be maintained or restored. Politically, this requires that broad coalitions of water users must work together towards a mutually acceptable future.

The best time to develop such coalitions is before water is allocated and before ecological crises occur. In many parts of the world, this opportunity was missed long ago. The potential for full or partial restoration remains, however. An ambitious example is taking place in south Florida, where water control structures are being physically removed and nutrient inputs curtailed in an attempt to encourage a more natural system (BOX 4). Other restoration projects around the nation also show promise.

The ecological consequences that arise when freshwater ecosystems are deprived of adequate water, proper timing of flows, and suitable water quality often become

BOX 3: THE GREAT LAKES ECOSYSTEMS

The Great Lakes – Superior, Michigan, Huron, Erie, and Ontario – hold 20 trillion cubic meters of fresh water, approximately 18 percent of the planet's fresh water supply. The overall basin is home to 35 million people, including 10 percent of the U.S. population and 25 percent of the Canadian population. Nearly 25 percent of agricultural production in Canada, and 7 percent of the agricultural production in the United States occurs in the basin. In addition, the Great Lakes provide drinking water for 40 million people and supply 210 million cubic meters of water per day for municipal, agricultural, and industrial use.

Poor water quality caused by excessive inputs of phosphorus and nitrogen is one of many serious problems affecting the Great Lakes. Some basins of the lakes also contain exceedingly high concentrations of toxic chemicals; habitat destruction has been significant and is increasing; native fisheries have been greatly altered or intentionally replaced; invasive species have altered native food webs and water quality and also damaged human infrastructure; and climate change is expected to alter lake levels. Although freshwater environments the world over share many of the same problems, their significance is heightened by the sheer size of the Great Lakes and the quantity and quality of their waters.

Water Quality. Water quality in the Great Lakes has improved dramatically from the eutrophic conditions that prevailed prior to the 1980s. This has been achieved through greater regulation of point-source pollution. However, water quality has not been restored to "natural condition." Years of phosphorus enrichment in Lake Michigan, for example, increased the growth of diatoms and depleted lake silica concentrations (silica is a necessary nutrient for diatoms and sinks to the lake bottom when diatoms die). Without enough silica, natural algal assemblages and the zooplankton that feed upon them have been severely altered. Today, cultural eutrophication may actually be masked by the filtering activity of zebra mussels, which increases water clarity by shifting nutrients from the water column to the lake sediments. Nonpoint source pollutants, including fertilizers, pesticides, sediment, and bacteria, still significantly impair Great Lakes water quality.

Invasive Species. Non-native species have modified habitats, reduced native biodiversity, and altered food webs. An estimated 162 exotic species now reside in the Great Lakes, including introduced sport fish. Although the zebra mussel and sea lamprey have received the most attention, many other less apparent species profoundly affect the ecosystem, including quagga mussels, predatory zooplankton such as *Cercopagis pengoi* and *Bythotrephes cederstroemi*, the benthic amphipod *Echinogammarus ischnus*, and the round and tubenose gobies. In addition to their ecological impacts, lamprey cost $10 million in control efforts each year, and zebra mussel control has totaled some $4 billion as of 2001.

Zebra mussel photo courtesy USGS.

Toxic Chemicals. The sediments in the Great Lakes store organic and inorganic contaminants coming from industrial, urban, and agricultural runoff as well as atmospheric deposition (including mercury and PCBs). Contaminants from sediments accumulate in aquatic species, affecting fish and wildfowl health and even the health of humans who eat contaminated fish. Contaminants also affect shipping, a major industry on the Great Lakes, because of potential restrictions on dredging of channels and harbors (which can release contaminants into the water column) and on disposal of dredged sediments.

Habitat Destruction. Land use changes have resulted in habitat loss throughout the Great Lakes basin. Urban sprawl continues to replace natural areas, farmland, and open space. The quality and quantity of coastal wetlands are declining; and the extent of hardened shorelines (that is, reinforced by sheet piling or rip rap) appears to be increasing, thus isolating wetlands from lakes, destroying habitat, and altering natural sediment movements.

Climate Change. Implications of future climate change in the Great Lakes region are profound. Some climate change models suggest conditions that will lead to lower lake levels, creating problems for the shipping industry as well as changes in water supply and environmental conditions in the lakes. Current climate models also suggest more extreme swings in climate, and unusually wet years may lead to periodic flooding. It is important to note that the 35 million people in the Great Lakes Basin are unprepared for large changes in lake level in either direction.

As an example of freshwater integrity, the Great Lakes fail on most accounts: shoreline hardening affects connectivity of the lakes with their wetlands; the current chemical and nutrient conditions represent a permanent change from natural conditions; and the plant and animal assemblages have been highly modified by human intervention. Constant effort and expense are now required to maintain water quality at acceptable levels, remove the legacies of past toxic inputs, control harmful non-native species, and restock valued recreational fisheries with exotic game fish that do not naturally reproduce in the lakes. Perhaps the Great Lakes can never be "restored" to the point where they are functionally self-sustaining, and therein lies a hard lesson. Many goods and services valued by society are no longer available (such as fisheries uncontaminated by toxins), and others are possible only through continuing expenditures of millions of dollars in remediation.

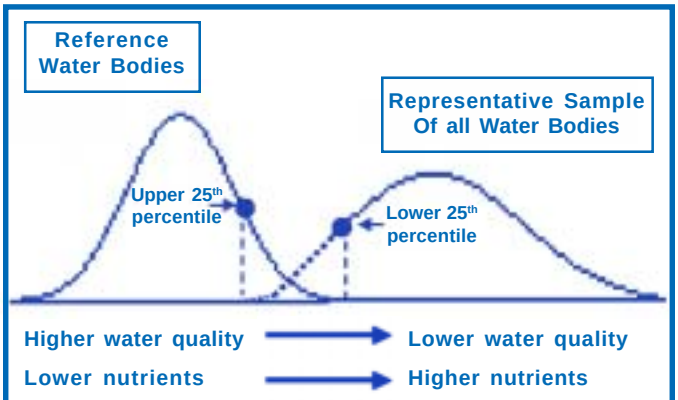

Figure 7—Two different approaches for establishing a standard or "reference condition value" for freshwaters. Reference condition values can be selected from waters that are representative of the most pristine, or least disturbed condition. If this goal is unrealistic, or if undisturbed water bodies no longer exist in the region, the reference condition value can be selected from among the least disturbed and polluted water bodies found in the region. Surveys of existing water quality from a broad range of water bodies are necessary in order to establish realistic water quality goals (Figure and text adapted from EPA 2000).

apparent to people only after the degradation begins to interfere with societal uses of fresh water. Nuisance algal blooms and loss of commercial or sport fisheries are examples of failures in ecosystem processes that were often years in the making. Some ecosystems naturally experience wide swings in environmental and ecological conditions from one year to the next that can mask gradual changes in physical and chemical factors. Most systems are inherently resilient to a particular pattern of disturbance, and their plant and animal communities will persist as long as conditions fluctuate within a certain range. Once a threshold is reached, however, these ecosystems may change rapidly to a new stable state that is very difficult to reverse. The collapse of a fishery and permanent cultural eutrophication from nutrient inputs are two examples of conditions that, once reached, make it difficult to restore the integrity of a freshwater system. Detecting such trends before problems become critical requires both monitoring the biological and physical conditions in freshwater ecosystems and understanding the natural ecological dynamics of these systems.

BALANCING HUMAN USE AND NEEDS OF FRESHWATER ECOSYSTEMS

The sustainability of aquatic ecosystems can best be ensured by maintaining naturally variable flows, adequate sediment and organic matter inputs, natural fluctuations in heat and light, clean water, and a naturally diverse plant and animal community. Failure to provide for these essential requirements results in loss of species and ecosystem services in wetlands, rivers, and lakes. Aquatic ecosystems can be protected or restored by recognizing the following:

1. Aquatic ecosystems are not simply isolated bodies or conduits but are tightly connected to terrestrial environments (Figure 8). Further, aquatic ecosystems are connected to each other and provide essential migration routes for species.

2. Dynamic patterns of flow that are maintained within the historical range of variation will promote the integrity and sustainability of freshwater systems.

3. Aquatic ecosystems additionally require that sediment loads, heat and light conditions, chemical and nutrient inputs, and plant and animal populations fluctuate within natural ranges, neither experiencing excessive swings beyond their natural ranges nor being held at constant, and therefore unnatural, levels.

Stating these requirements for maintaining aquatic ecosystem integrity, of course, is not the same as implementing them in the context of today's complicated society. U.S. water policy currently supports increased exploitation of water supplies in order to meet human demands. Policies for maintenance of water quality and flow are primarily based on human health needs. The age of ever-increasing exploitation is over, however. We must begin to redefine water use based on the recognition that supplies are finite and that healthy freshwater ecosystems must be sustained or restored. For these reasons we offer the following recommendations for how water is viewed and managed:

1. Incorporate freshwater ecosystem needs, particularly naturally variable flow patterns, into national and regional water management policies along with concerns about water quality and quantity.

Because most land and water use decisions are made locally, we recommend empowering local groups and communities to implement sustainable water policies. A large and growing

Figure 8—Even isolated lakes are linked to the land and water around them through the flow of freshwater. Photo courtesy J. Boles, California Department of Water Resources

BOX 4: RESTORING FRESHWATER ECOSYSTEMS IN SOUTH FLORIDA

The south Florida ecosystem covers approximately 47,000 square kilometers and ranges from Orlando in the north to the Florida Keys at its southern extreme. It includes the Kissimmee River, Lake Okeechobee, The Everglades, and Florida Bay. The landscape is essentially flat; the elevation drop from Lake Okeechobee to Florida Bay, a distance of 160 kilometers, is less than 6 meters. South Florida has undergone enormous changes in population, land use, and hydrology over the past 100 years, resulting in profound changes to ecosystem structure and functioning. Starting in the early 1900s, efforts were made to drain the Everglades wetlands, which were viewed as wastelands and useless swamps. Hurricanes and floods prompted massive water management projects. There are now more than 2,500 kilometers of levees and canals, 150 gates and other water control structures, and 16 major pump stations. The flood control system has worked remarkably well, making the region less vulnerable to the extremes of flooding and drought by storing water for supply and moving it for flood control. These management projects were designed in the 1950s when it was anticipated the population in the region would reach 2 million by the year 2000. Today, however, the region is home to more than 6 million people. More significantly, the water projects were not designed with environmental protection or enhancement in mind.

Environmental problems unintentionally created by these water management projects include:

(1) Up to 6.4 billion liters per day of excess rainwater is channeled directly to the ocean to keep urban and agricultural lands from flooding, causing salinity imbalances in estuaries and influencing plant and animal communities.

(2) Lake Okeechobee is treated as a reservoir for water supply or flood control instead of as a natural lake.

(3) Water supply and periodicity for the Everglades has been altered, greatly harming the biota.

(4) And Water quality has deteriorated throughout the region.

Accelerated eutrophication of Lake Okeechobee from phosphorus runoff associated with dairy and beef cattle operations, for example, has shifted the composition of the algal, invertebrate, and higher plant community and thus, the food web. Phosphorus enrichment of the northern Everglades from sugar cane farms has changed the structure and biomass of the periphyton community (organisms attached to submerged substrates) while increasing cattails at the expense of sawgrass. Increases or decreases in the discharge of fresh water to estuaries have influenced the natural salinity patterns of these systems, affecting the abundance of seagrass, oyster, and fish communities. Channelization of the Kissimmee River caused the loss of 11,000 hectares of floodplain habitat.

Approximately half of the historic Everglades has been converted to agricultural or urban use. Populations of wading birds have been reduced 85 to 90 percent. Sixty-eight species of plants and animals in south Florida are threatened or endangered, and invasive species such as melaleuca, Brazilian pepper, Australian pine, torpedo grass, Old World climbing fern, and Asian swamp eel are threatening native habitats and species.

Although it is not possible to restore this region to its pristine condition, efforts are underway to redesign the south Florida aquatic environment to make it more compatible with the way the system formerly functioned. Congress has funded efforts to develop a Comprehensive Everglades Restoration Plan, an ambitious and innovative partnership that aims to enhance the region's ecological and economic values as well as the well-being of its human population. The objectives are to increase the amount of water available by storing it instead of sending it out to sea, ensure adequate water quality, and reconnect the parts of this ecosystem that have been disconnected and fractured. A multi-faceted approach has been proposed that may take 25 years or more to implement.

The ecological goals of the plan are to increase the extent of natural areas, improve habitat and functional quality, and improve native species richness and biodiversity. Success will be evaluated with quantitative criteria. For example, a goal for Lake Okeechobee is to reduce total phosphorus in the water column from a current concentration of 110 to 40 µg/L. Rigorous programs of scientific research will continue throughout project implementation in order to address major uncertainties. The information generated, combined with results from monitoring networks, will be used in adaptive management of the restoration plan.

The inflow and water distribution works for STA 1 (stormwater treatment area), which is a large constructed wetland that is treating runoff from sugar cane fields before entering the Everglades. Photo from the South Florida Water Management District archives.

number of watershed groups is already moving in this direction with the support and guidance of state and federal agencies. Flexibility, innovation, and incentives such as tax breaks, development permits, conservation easements, and pollution credits are effective tools for achieving freshwater ecosystem sustainability goals.

2. Define water resources to include watersheds so that fresh waters are viewed within a landscape or systems context.

Many of the problems facing freshwater ecosystems come from outside the lakes, rivers, or wetlands themselves. Laws and agency regulations lag in their recognition of this fact. One place to initiate a change is through existing governmental permitting processes. Requests to the Federal Energy Regulatory Commission for hydropower dam renewals, permit requests to the Army Corps of Engineers for dredge and fill operations under the Clean Water Act Section 404, and land use and effluent discharge permit requests to state, county, and local entities present ideal opportunities to integrate ecosystem needs with traditional water uses. The EPA's TMDL Program is an effort to address both point and nonpoint pollution from a watershed to a water body, although the program has not yet been fully implemented. It should also be refined to consider how flow variability influences the transport of pollutants.

3. Increase communication and education across disciplines.

Interdisciplinary training and experience, particularly for engineers, hydrologists, economists, and ecologists, can foster a new generation of water managers and users who think about fresh waters as systems with ecological purposes as well as water supply functions.

4. Increase restoration efforts for wetlands, lakes, and rivers using ecological principles as guidelines.

While some restoration has occurred, a greater effort is required to restore the ecological integrity of the nation's water resources. The goal of restoration should be to reinstate natural variations in the fundamental environmental factors identified above. Yet many restoration projects, especially for wetlands, have focused only on replanting vegetation while ignoring underlying hydrologic, geomorphic, biological, and chemical processes. Highly visible yet ecologically incomplete restoration efforts such as these wetland revegetation projects may even foster complacency among the public. A recent Gallup Poll found that Americans are increasingly satisfied with the nation's environmental protection efforts, making them less likely to support the funding and political effort needed to enact genuine ecological restoration requirements. In any given freshwater system, the extent of restoration and protection that is eventually undertaken will be widely debated because active management is inherently a social process, although one ideally informed by science. Restoration efforts can encompass a spectrum of goals, from nearly full recovery of native species and environmental conditions to the management of dynamic, biologically diverse communities that do not necessarily resemble native ecosystems.

5. Maintain and protect remaining minimally impaired freshwater ecosystems.

Aldo Leopold said: " If the biota, in the course of aeons, has built something we like but do not understand, then who but a fool would discard seemingly useless parts? To keep every cog and wheel is the first precaution of intelligent tinkering." Many restoration projects fail to reestablish ecosystem functioning once major processes have been disturbed. It is far wiser and cheaper to conserve what we have. Moreover, our remaining functionally intact freshwater ecosystems can provide a source of plant and animal colonists for restoration projects elsewhere.

6. Bring the ecosystem concept home.

Achieving ecological sustainability requires that we come to recognize the interdependence of people and the environments of which they are a part (Figure 9). For fresh waters, this will require broad recognition of the sources and uses of water for societal and ecological needs. It will also require taking a much longer view of water processes. Water delivery systems and even dams are developed with life spans and management guidelines of decades to, at most, a century. Freshwater ecosystems have evolved over aeons, and their sustainability must be considered from a long-term perspective. Governmental policies, mass media, and a market-driven economy all focus on much shorter-term benefits. Educational programs at the kindergarten through high school level, individual initiatives to become informed, and efforts by local watershed groups interested in protecting their natural resources can provide good first steps toward enduring stewardship. These steps must be matched by

Figure 9—Urban stream in Denver, Colorado. Photo courtesy the U.S. Geological Survey, South Platte National Water Quality Assessment Program (NAWQA).

state and national acknowledgment that fundamental human needs for water can only be met in the future through policies that preserve the integrity and functioning of freshwater ecosystems today.

CONCLUSION

Freshwater ecosystems have been described as "biological assets (that are) both disproportionately rich and disproportionately imperiled." They need not be so threatened. By recognizing the need for naturally varying flows of water and sediment, and reduced pollution loads, we can maintain or restore freshwater ecosystems to a sustainable state that will continue to provide the amenities and services society has come to expect while helping native aquatic species to flourish.

ACKNOWLEDGMENTS

This paper benefited from discussions with Neil Grigg, Alan Covich, Rhonda Kranz, and Dennis Ojima, and reviews from Penny Firth, Lou Pitelka, Stuart Findlay, Steve Carpenter, Pam Matson, Julie Denslow, Judy Meyer, and the Public Affairs Committee of the Ecological Society of America.

SUGGESTIONS FOR FURTHER READING

This report summarizes the findings of our panel. Our full report, which is published in the journal Ecological Applications (Volume 12, Number 5: 1247-1260), discusses and cites extensive references to the primary scientific literature on this subject. From that list we have chosen those below as illustrative of the scientific publications and summaries upon which our report is based.

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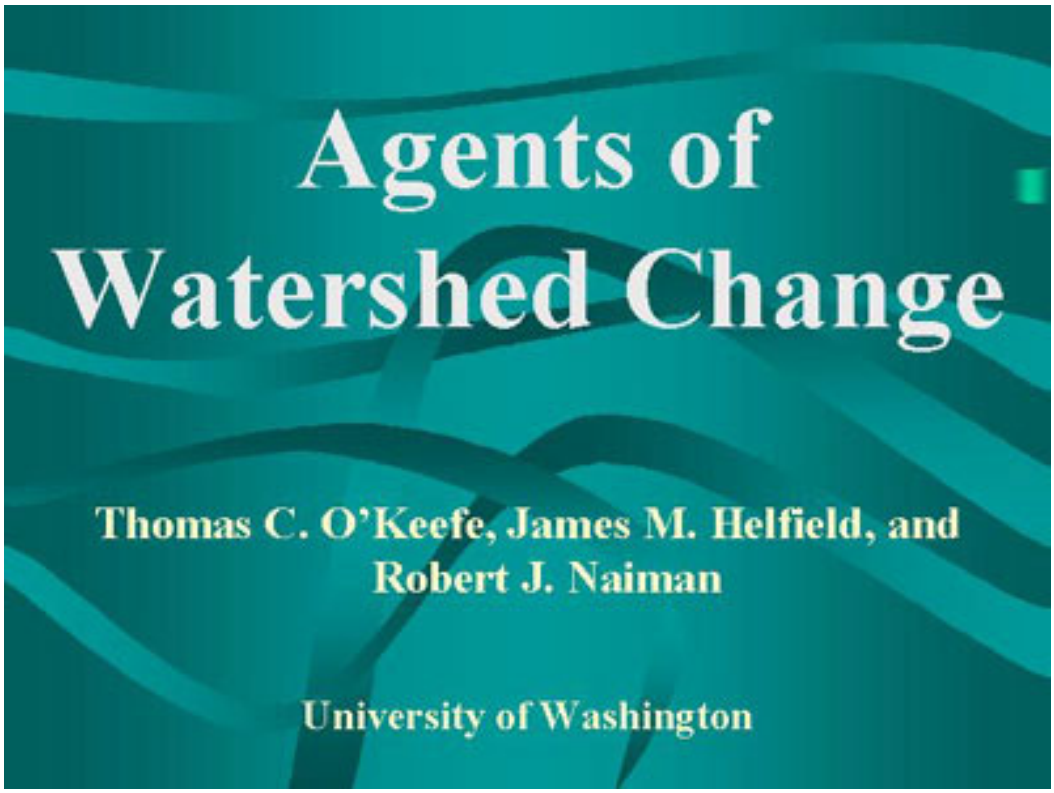

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Introduction

This training module provides an overview of natural and human-made change processes and the ways in which they affect the structure and function of watersheds. The module has four primary sections (Figure 1):

Figure 1

- an introduction to the role of change in the watershed,
- descriptions of specific natural agents of change and their ecological effects,
- descriptions of specific human-made agents of change and their ecological effects, and
- a discussion of the watershed processes most vulnerable to change.

Change is a natural, essential feature of watersheds. Being able to identify different change processes, understand the differences between natural and human influences on watershed change, and recognize a change of concern are all critical for effective watershed management. Watershed change, however, can be very complicated to understand and manage when many human and natural causes of change interact as they often do.

After completing this training, the participant should know the major changes affecting watersheds and understand that watersheds are dynamic systems. Some background in watershed ecology is helpful for understanding the material presented here and can be obtained from the module, ***Introduction to Watershed Ecology*** at http://www.epa.gov/watertrain/ecology.

The training goals of this unit are to:

1) Introduce basic characteristics of watershed change

2) Describe the different sources and effects of natural and human-made watershed change

3) Provide examples of how these changes affect watershed condition

The Concept of Change

Figure 2

Flowing water is a source of continual change in river corridors

Figure 3

Change is an integral component of the watershed (Figure 2). The wide variations in river and stream flow regularly change shorelines, stream channels and stream corridors (Figure 3). Upland areas of watersheds also undergo changes due to ecological succession, disease, competition, human activity and other factors. Even when virtually undisturbed by man, the physical and biological characteristics of ecosystems do not remain constant over time, as plant and animal communities are continually altered in response to changes in each other and in the watershed's physiographic and climatic conditions. Natural changes do cause adverse effects on some components of the ecosystem, while benefiting others with new opportunities.

The processes and events that cause these changes are generally called **disturbance** or sometimes **stress** (Figure 4). The former term implies any change to a watershed's physical or biological characteristics, and the latter term is a more value-laden word that implies the adverse effects that change usually has on some part of the ecosystem.

Terms like **dynamic equilibrium** (Figure 5) are used to describe the state of existence in which ecological communities exist through and are modified by change. In many cases, periodic disturbance is required to foster ecological processes (e.g., flooding promotes nutrient cycling in riparian soils), or to complete the life cycles of various organisms (e.g., many coniferous trees rely on fire for seed release and dispersal). A certain amount of change is therefore unavoidable, essential and desirable in watershed ecosystems. For this reason, a key element in any concept of ecosystem health is an ecosystem's ability to evolve over time and to self-regulate following disturbance (Steedman and Regier 1990).

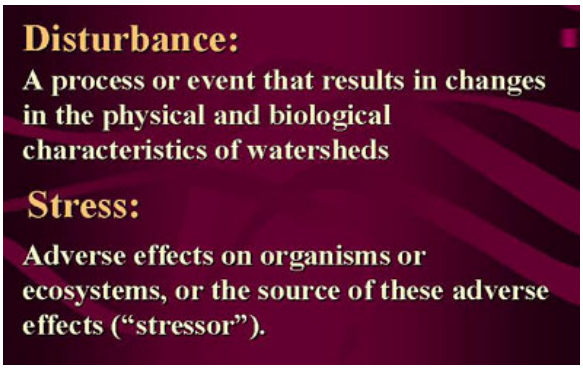

Disturbance:
A process or event that results in changes in the physical and biological characteristics of watersheds
Stress:
Adverse effects on organisms or ecosystems, or the source of these adverse effects ("stressor").

Figure 4

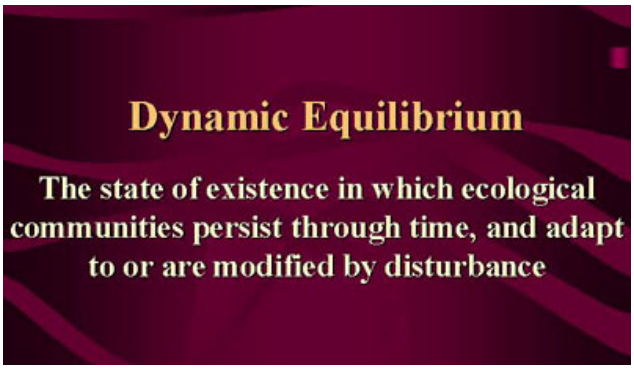

Dynamic Equilibrium
The state of existence in which ecological communities persist through time, and adapt to or are modified by disturbance

Figure 5

Take a moment: *Think about the main types of change occurring in your watershed. What changes mostly involve natural components of the watershed ecosystem? What changes in the human community are occurring in your watershed? Are these changes or their magnitude new or unprecedented? What do you think is the outlook for your watershed's human and natural changes, in terms of dynamic equilibrium? You may wish to revisit these questions after completing this module.*

Scale Concepts

Environmental change is caused by a wide range of processes occurring through space and over time (Figure 6). As a basic conceptual framework, think of a watershed as a system incorporating a series of subsystems at smaller spatial scales (e.g., watershed > river corridor > tributary > reach > pool/riffle habitat > microhabitat spaces among cobblestones), each of which are affected by disturbances occurring at time intervals and spatial scales that are (as a very general rule) proportionally related to the magnitude of the subsystem (Table 1). Scale is essential to evaluating change because the significance of a given change is very different from scale to scale. For example, channel form and streamside vegetation may seem constant when viewed over a time frame of months or a few years, but may be highly variable when viewed over a time scale of decades or longer. Similarly, a forest fire may be considered a rare and catastrophic event within the lifetime of a stand of trees, but the same fire may be a natural part of a larger cycle of recurrent fires when considered over a geological time scale.

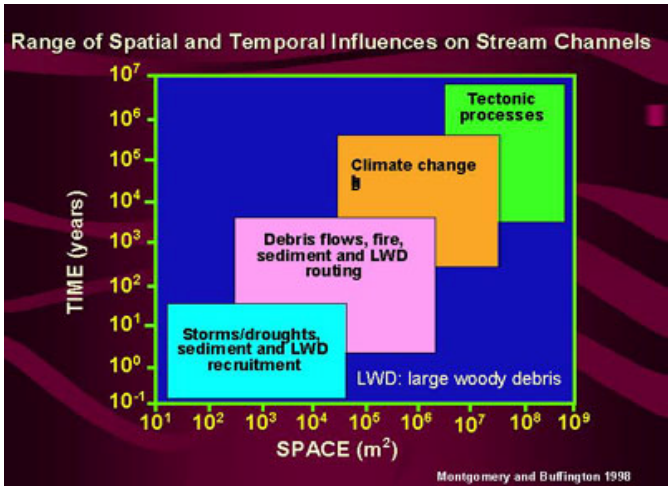

Range of Spatial and Temporal Influences on Stream Channels
TIME (years)
SPACE (m²)
Tectonic processes
Climate change
Debris flows, fire, sediment and LWD routing
Storms/droughts, sediment and LWD recruitment
LWD: large woody debris
Montgomery and Buffington 1998

Figure 6

Some events or processes controlling stream habitat on different spatiotemporal scales (from Frissell et al. 1986).				
Stream System	**Linear Spatial Scale (m)**	**Evolutionary Events**	**Developmental Processes**	**Time Scale of Potential Persistence (years)**
Stream	10^3	Tectonic uplift, subsidence; catastrophic volcanism; sea level changes; glaciation, climatic shifts	Planation; denudation; drainage network development	10^6-10^5
Segment	10^2	Minor glaciation, volcanism; earthquakes; very large landslides; alluvial or colluvial valley infilling	Migration of tributary junctions and bedrock nickpoints; channel floor downcutting; development of new first order channels	10^4-10^3
Reach	10^1	Debris torrents; landslides; log input or washout; channel shifts, cutoffs; channelization, diversion or damming by man	Aggradation/degradation associated with large sediment-storing structures; bank erosion; riparian vegetation succession	10^2-10^1
Pool/ Riffle System	10^0	Input or washout of wood, boulders, etc.; small bank failures; flood scour or deposition; thalweg shifts; numerous human activities	Small-scale lateral or elevational changes in bedforms; minor bedload resorting	10^1-10^0
Micro-habitat system	10^{-1}	Annual sediment, organic matter transport; scour of stationary substrates; seasonal macrophyte growth and cropping	Seasonal depth, velocity changes; accumulation of fines; microbial breakdown of organics; periphyton growth	10^0-10^{-1}

Table 1

There is a distinction to be made between **evolutionary events** (Figure 7), which are extrinsic forces that create, significantly modify, and destroy systems at a given scale, and developmental processes, which are intrinsic, progressive changes following a system or subsystem's genesis or change as a result of an evolutionary event (Frissell et al. 1986). For example, global climate change may result in a shift in the

Evolutionary Events
Intrinsic forces that create and destroy systems at a given scale
Developmental Processes
Intrinsic, progressive changes following a system's change as a result of an evolutionary event

Figure 7

distribution of a various tree species. In this case, climate change represents a large-scale evolutionary event resulting in a predictable set of developmental processes (i.e., shifts in forest community composition) at smaller scales. Similarly, a 100-year flood may be seen as an evolutionary event that scours away and destroys floodplain vegetation communities, giving rise to developmental processes such as forest succession in affected habitats.

Characterizing Change

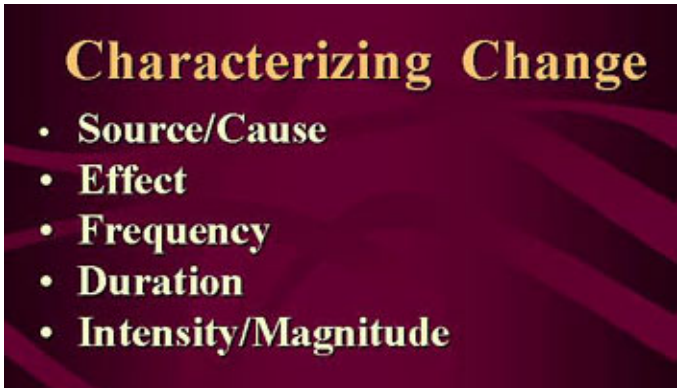


Figure 8

Different types of changes are usually described in terms of the **sources** or **causes** of change and the **effects** they bring about in the watershed ecosystem (Figure 8). In addition to the type of change that occurs, disturbance processes are typically characterized according to the **frequency** of occurrence, as well as the **duration** of their effects. In general, geological processes and climate cause the primary natural changes affecting higher levels of organization (i.e., the larger-scale watersheds) over long periods of time. Within the context of these larger-scale and long-term processes, ongoing frequent and smaller-scale processes also produce change.

Change processes may also be characterized according to the **intensity** or **magnitude** of their effects. Intensity of disturbance is typically defined according to the magnitude of effects on biotic communities, but can imply physical effects as well (e.g., magnitude of a flood or the quantity of sediments it has moved).

Frequency and intensity of change can highly influence plant and animal communities; species associated with frequently disturbed habitats tend to develop adaptations that allow them to persist or even thrive under those conditions. For example, trees growing in low floodplains subjected to frequent flooding often produce adventitious roots that allow for oxygenation following burial by water and sediment. In dry, upland forests, species such as ponderosa pine withstand frequent fires through such adaptations as the development of thick, fire-resistant bark and dropping of lower limbs to minimize the spread of fire to the crown. Within many watersheds, upper reaches are often prone to infrequent, high-intensity events (e.g., landslides, debris flows), whereas lower reaches tend to be affected by frequent, low-intensity events (e.g. sediment transport and redeposition).

The frequency and intensity of such changes as flooding, windstorms, hurricanes, and brush fires also heavily influence land use planning decisions for many communities, who are often placed in a position of continually evaluating and managing risks versus potential benefits. Examples include southeastern US coastal communities' interactions with hurricanes, and the recurrent flood management decisions of many US towns located on river floodplains. Thorough understanding of all aspects of potential changes can help these communities make sound decisions.

Changes of Concern (Figure 9)
Environmental changes almost always benefit some species to the detriment of others. Accordingly, **environmental degradation** is a subjective, value-laden concept influenced by different ideas of desired environmental conditions. Changes that markedly decrease populations of favored wildlife or plant species, or limit a watershed's ability to provide resources for human communities (e.g., potable water, food/fiber, aesthetics) are widely seen as degradation especially by affected people.

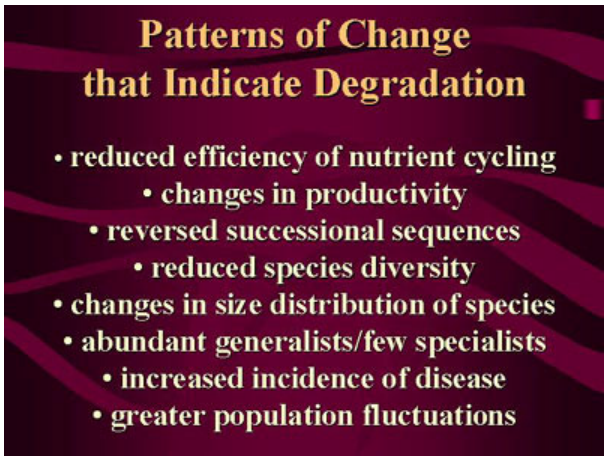

Patterns of Change
that Indicate Degradation
• reduced efficiency of nutrient cycling
• changes in productivity
• reversed successional sequences
• reduced species diversity
• changes in size distribution of species
• abundant generalists/few specialists
• increased incidence of disease
• greater population fluctuations

Figure 9

But, besides these human examples, other patterns of significant change are also symptomatic of degradation; these types of change are not necessarily related to human values or perceptions, but adversely affect ecosystems in ways beyond what is immediately useful to man. These changes include reduced efficiency of nutrient cycling, changes in productivity, reversed successional sequences, reduced species diversity, changes in size distribution of species, increased abundance of tolerant "generalist species" relative to "specialists", increased incidence of disease, and greater population fluctuations (Steedman and Regier 1987).

Changes that produce significant, widespread and/or long-term degradation are **changes of concern** (Figure 10). These types of changes alter the ways in which ecosystems organize, remain functional, and evolve over time, and threaten the abilities of ecological communities to recover and persist following periodic disturbance. Change of concern in the watershed may be defined as the significant alteration or loss of a primary watershed process or structural component that persists beyond normal cyclical change (e.g., seasonal change).

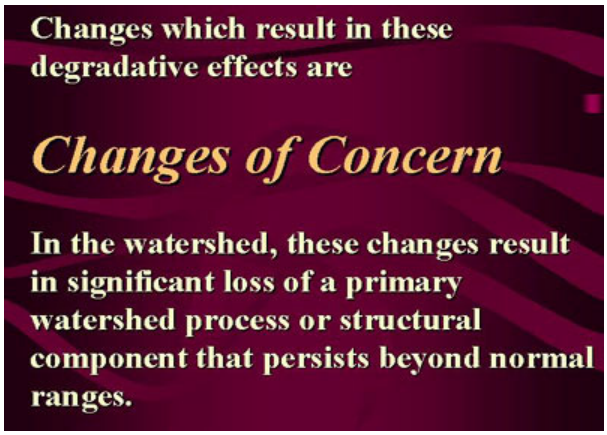

Changes which result in these degradative effects are
Changes of Concern
In the watershed, these changes result in significant loss of a primary watershed process or structural component that persists beyond normal ranges.

Figure 10

Changes of concern are most often related to a human-made cause or to the high-magnitude, cumulative effects of human-made plus natural agents acting together. Except for major evolutionary events discussed earlier, purely natural changes are often not permanently degrading to whole ecosystems because these ecosystems developed in adaptation to these very same changes. As human-made changes are very recent and often very intensive changes, they have not been easily accommodated by ecosystems and thus can lead to more significant and long-lasting degradation.

Nevertheless, it is also possible to consider any change as a change of concern if its "temporary" disruption is unacceptable on human time scales (e.g., duration in human rather than geologic terms) – consider, for example, earthquakes at the San Andreas fault, or a forest fire near a residential community that treasures its nearby woods. Although many natural changes can reach

magnitudes often called "natural disasters," still they represent changes from which watersheds can and do eventually recover, often with different ecological features than before. Human evaluation of the seriousness of natural disasters relates closely to the time scales necessary for recovery of the ecosystem components valued by people.

It is very important to note that many human-made changes of concern are not unavoidable, and considerable progress has been made in understanding human influence on change and how to manage our impacts. Rather, one of the biggest problems is limited awareness of the necessary remedies and a related unwillingness to use them. A major challenge for the watershed manager is to recognize when a change – or the risk of a future change – represents a potentially damaging change of concern rather than a temporary, recoverable change that will leave ecological processes and valued attributes of the watershed intact and functional. When an environmental change proceeds past a certain threshold level, it often results in a change of state at which previous relationships within the ecosystem no longer hold.

> ***Take a moment:*** *Earlier you were asked to think about changes of all kinds in your own watershed. Do you now feel that any of these changes are changes of concern? To whom or what are they of particular concern? Is your judgment based on these changes causing losses of things valued by people, based on losses of key ecosystem features or functions, or based on both?*

Agents of Natural Change in Watersheds

Agents of change may be naturally occurring or anthropogenic (Figure 11). In many cases, change involves interactions between human and natural processes. First, this module will provide brief descriptions of several agents of natural change processes, along with their general effects on watersheds. Then in the next section, a series of human-made agents of change will be discussed.

Figure 11

Natural Change Processes

The natural agents of change listed in Figure 12 all have had important direct impacts on watershed ecosystems and their evolution over countless centuries. There are many additional natural change agents beyond those listed and discussed here.

Figure 12

Natural Change Processes: Flooding

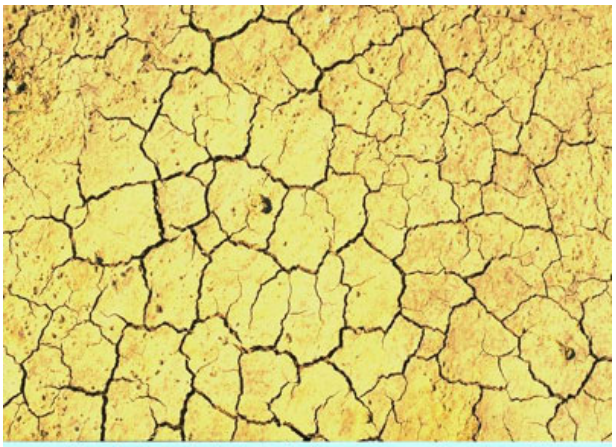
In rivers and streams, floods are critical for several reasons (Figure 13). They redistribute organic material and living organisms downstream and create an opportunity for exchange of sediment and nutrients with the floodplains. Major structural elements of the channel are redistributed during floods and new surfaces are exposed. During particularly intense floods entirely new channels can form, riparian forests can be displaced, and major landslides and debris torrents can be triggered, leading to a more extensive ecological recolonization and recovery period.

Major flooding effects on a Virginia river (left) included the flattening of riparian forest trees; the most visible effect on a nearby small stream (right) was soil erosion.

Figure 13

Variation in flow on a seasonal and interannual basis is a primary selective force for organisms living in rivers and their associated watersheds. Floodwaters also play a major role in shaping the physical environment of the stream channel and floodplains. For example, the bankfull flood stage (a flood level which fills the main channel and just begins to spill onto the floodplain), which is a flood level that recurs approximately every 1.5 years on average, is recognized as the primary force in determining the shape of the channel and the location of its floodplains. The amount and velocity of streamflow and the shape of the channel affect the size of materials transported and the stability of the streambed, which in turn affect the density and composition of benthic organisms. Across much of North America, seasonal floods are associated with the spring snowmelt. In other parts of the country, floods occur during extreme weather events such as hurricanes (southeast coastal areas) or periods of extended rain.

Natural Change Processes: Drought



Cracked mud of a lake bottom exposed by drought

Figure 14

In addition to its obvious adverse effect of significantly reducing overall water volume or flow, drought can have a major impact on water chemistry by altering the relative contribution of groundwater versus surface water (Figure 14). This can in turn result in changes in the water chemistry, transparency, light regime, and thermal characteristics of lakes and rivers. Drought also may totally dry up temporary water bodies such as woodland ephemeral pools, small streams with marginal flow, or seasonal, pothole-type wetlands. Many organisms are uniquely dependent upon these ephemeral waters that are absent from the landscape during periods of drought. For several species of birds and amphibians, the disappearance of seasonal water bodies during times of drought can have a detrimental effect on the population due to temporary elimination of breeding or feeding grounds. Many years of depressed population numbers in these species can follow droughts. Other species, including most microcrustaceans, many other amphibians, and even some species of fish can wait out periods of drought by going through a stage of dormancy that, in the case of some crustaceans, can last up to hundreds of years.

Beyond affecting the water body and its aquatic organisms, drought significantly affects upland areas of watersheds. Severe drought can cause dieback of less-tolerant tree and shrub species and lead to shifts in dominant vegetation. Crop failures from sustained droughts can eventually lead to abandonment of some areas' agricultural land uses and communities. As witnessed in the "dust bowl" years, droughts can also liberate huge volumes of topsoil that is no longer stabilized by crops or natural vegetation. This may have severe effects on water quality and on productivity of the topsoil-deprived lands as well as the new sites of deposition.

Natural Change Processes: Fire

Crown fires burn hotter and can cause stand replacement, unlike surface fires which consume leaf litter and promote germination and growth of more conifers.

Figure 15

Fire frequencies and intensities are controlled by soil moisture, ignition sources (e.g., lightning) and fuel buildup (i.e., amounts and combustibility of litter) (Figure 15). In North America, fires in coniferous forests typically occur during dry summer periods, and dry upland areas are generally more prone to fire than riparian areas. Longer intervals between fires entail greater fuel buildups and correspondingly more intense fires when they do occur. There

is a distinction to be made between surface fires, which tend to occur at frequent intervals (1 to 10 years) and burn at low intensities (200 to 800 kW/m), and crown fires, which occur less frequently (100 to 1,000 years) and burn at high intensities (>50,000 kW/m). Crown fires tend to do more damage to trees and are more likely to initiate stand replacement by other, pioneer species.

Fires in and around Yellowstone National Park (Figure 16) burned over 250,000 ha in 1988, a major disturbance event which likely occurs on intervals of 100-300 years (Turner et al. 1997). The spatial pattern of fires on the landscape could not be predicted by landscape characteristics. Instead, fire spread was determined largely by wind speed and direction. Although the Yellowstone fires are often thought of as a single event, individual burns created a heterogeneous mosaic across the landscape. Low intensity surface burns occurred in some areas while high intensity crown fires occurred in other areas.

Frequent low-intensity fires play an important role in shaping various forest associations. Species such as lodgepole pine and jack pine rely on heat from fires to open cones and allow seeds to disperse, while exposed mineral soils following fire encourages germination of pine seeds. In some areas, fire resistance adaptations (e.g., thick bark, dropping of lower limbs to prevent fire ladder effects) allow species like ponderosa pine and red pine to withstand periodic low-intensity fires, maintaining open stands with minimal shading and competition for soil resources from other species. More intense fires kill off mature trees, creating open conditions for early successional species such as alder, which fixes nitrogen to contribute to soil and litter pools. Small, patchy fires (Figure 17) help maintain a mosaic of different seral communities within a given watershed, thereby increasing habitat complexity and diversity.

Wildfire effects on water quality can vary widely. Very intense fire can volatilize important nutrients needed by terrestrial plants, but less intense fires can mobilize nutrients for rapid uptake and growth (FISRWG, 1998). Large-scale fires in a watershed with steep slopes can accelerate erosion and runoff, raise water temperatures due to removal of riparian cover, and leave a watershed more vulnerable to other disturbances for a period of years.

Regrowth of pines following the Yellowstone National Park wildfires of 1988

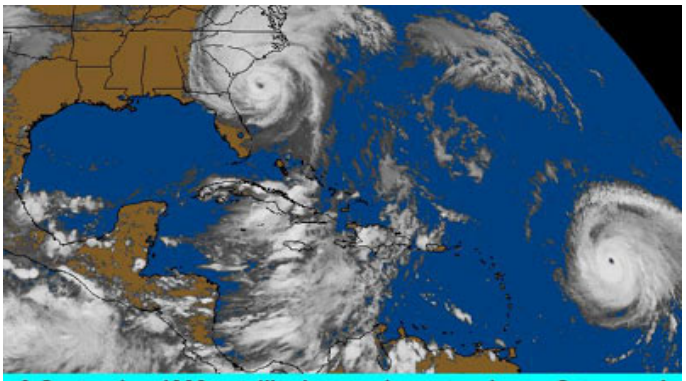
Figure 16

Small fires like this one in Wenatchee, WA help maintain a mosaic of different plant communities within a given watershed, thereby increasing habitat complexity.

Figure 17

Natural Change Processes: Windstorms

Windstorms are one of the many factors responsible for maintaining the spatial mosaic of different vegetation communities that exists across the landscape (Figure 18). Extreme windstorms, such as tornadoes in the Central US and hurricanes in the Southeastern US, occur regularly. In the Pacific Northwest, ten known storms with hurricane force winds have hit the coast in the last 200 years. Two of these storms had winds in excess of 150 mph. Many hurricanes, as well as simply high winds over sustained periods of time, have deforested areas of hundreds to thousands of square miles. In 1999, for example, 25% of the Boundary Waters Canoe Area of Minnesota was deforested in a massive blowdown not associated with a hurricane.



A September 1999 satellite image shows two large, Category 4 hurricanes (Floyd and Gert: up to 155 mph winds) approaching the US coast. Wind and rain damages from Floyd extended from the Carolinas through New England.

Figure 18

The effects of a windstorm can depend greatly on the local topography and the vegetation present (Figure 19). Disturbance associated with wind can thus be quite patchy. The ability of a given tree to withstand a windstorm depends on not only the energy of the wind, but the exposed surface area of the tree, its root mass, and the characteristics of the soil it is rooted in. Small groves of old-growth trees found in second growth forests can be especially susceptible to windstorms. Blowdown patches form open areas that become habitat for edge-preferring plant and animal species. Synergy between windstorms and pest outbreaks is evident when a disease weakens a stand of trees that later become victims of high winds. There can also be interactions between human land use and the effects of windstorms, as when removing natural windbreaks makes remaining vegetation more susceptible to windthrow.

Substantial damage to mature trees occurs during hurricanes, but regrowth can be rapid

Figure 19

Wind can affect water quality and aquatic ecosystem health, for example, by adding significant quantities of windblown soil to the water. Wind events are often responsible for transporting debris and in some cases organisms to different areas of the lake. Even non-extreme winds play an important role in determining when a lake stratifies or destratifies and the length of time that it retains an ice cover. The timing of lake turnover in the fall, for example, depends on the relative strengths of wind energy and the water's buoyant resistance to mixing.

Natural Change Processes: Erosion and Sediment Deposition

Despite the fact that erosion can dramatically affect water quality, it is a natural process (Figure 20). Sediment erosion, transport and redeposition are among the most essential natural processes occurring in watersheds. In fact, cutting off sediment supply (as when an impoundment intercepts cobbles, gravels and smaller particle sizes normally transported downstream as a stream's bedload) can lead to dramatic shifts in streambed composition and stream downcutting, among other effects.

Sediment eroded from a wilderness area upstream enters a California river; the natural balance of erosion and deposition replaces sediments carried downstream with sediments of similar quantity and particle size from upstream.

Figure 20

Although sediment may enter a river from adjacent banks, most is transported from upstream sources. Sediment supply can be a major factor in determining channel morphology, which in turn determines many of the primary physical and biological characteristics of a river. During the 1964 floods of Northern California and Southern Oregon, for example, channel widths doubled and channel beds aggraded up to 4 meters in response to increased sediment loads. Sediment transport depends on the interaction between upland topography, which represents the source of sediments, and discharge regime, which supplies the kinetic energy for their distribution in the river channel. The vegetation cover, climate, soil type, and slope gradient can all influence the location and nature of erosion. Dramatic changes can occur, for example, when intense rainstorms cause landslides or when a stand-replacing fire changes the vegetation cover on a hill slope. It is important to note that in most parts of the watershed erosion, transport and deposition do not occur at constant rates, but are highly active during events such as flooding, windstorms, ice scour, and seasonal or drought-induced exposure of soils.

The relationship of transport capacity to sediment supply determines the channel response to inputs of sediment. Widening and aggradation of the channel, pool filling, and braiding can all occur when sediment supply overwhelms the ability of the river to transport it. Channels with too-high sediment supply tend to be unstable and have multiple active channels separated by bars.

Natural Change Processes: Climate Change

Although there is strong evidence of human-induced climate change effects, climate change has long been a natural agent of change occurring gradually over broad spatial scales (Figure 21). Climatic conditions and atmospheric CO_2 concentrations have been variable on a scale of glacial-interglacial cycles, as evidenced by analyses of gas bubbles in Antarctic ice, simulations by atmospheric circulation models, estimates of global ice volume, and paleolimnological analyses of pollen grains in lake and bog sediments. These paleo-records of climate clearly indicate that climate has varied due to natural causes on time scales from decades to millions of years. The present warm period began approximately 10,000 years ago with the end of the last ice age. Within this time, minor fluctuations have occurred in climate. The Medieval Warm Period reached its peak in the 12th and 13th centuries. This was followed by considerably colder climate that lasted until about 1890 referred to as the "Little Ice Age". During this period mean global temperatures were approximately 0.5-1.0°C cooler than today. On even shorter time scales (years to decades), the El Niño phenomenon has widespread effects on global climate. In general, the dominant tree species in North America today have probably become common only within the past 10,000 years, and have likely attained their current distribution within the last 3,000 - 5,000 years (Brubaker 1988).

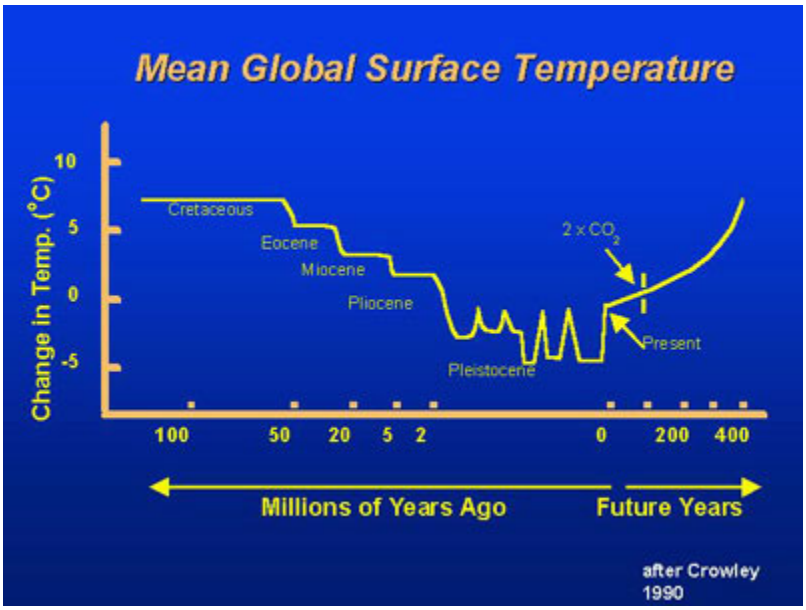


Figure 21

This process has potentially important implications for long-term watershed management, particularly in parks and wilderness areas that have been established to preserve certain species or communities. Over the life span of long-lived species, climate may change to the extent that subsequent generations will not reproduce effectively in protected areas. For example, the oldest populations of giant sequoia in California national parks experience generally drier conditions relative to when they were established, 2,000 - 3,000 years ago. As a result, seedling establishment may be hampered and populations may be in decline. Vegetation responds to climate at the level of the individual species rather than as an intact assemblage of species. As climate changes in the future, we should therefore expect the formation of new communities rather than the simple displacement of existing communities to new locations (Crowley 1996).

Natural Change Processes: Glacial Movement

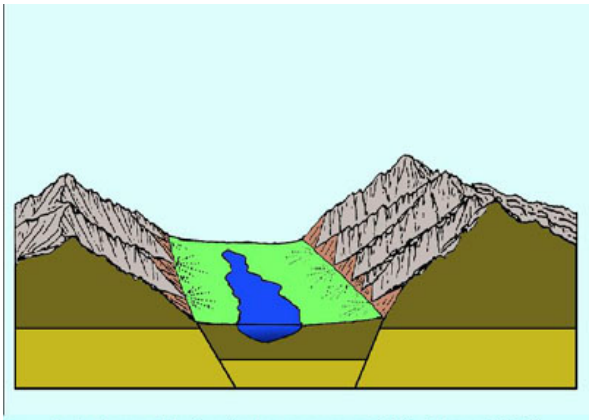
Glaciers have transported sediment, carved the landscape, modified vegetation, and redistributed fish and wildlife.

Figure 22

On the time scale of human lives, lakes and river valleys appear to be relatively permanent features on the landscape (Figure 22). On a geological time scale, however, they are ephemeral. Pleistocene glaciation (12,000-15,000 years ago) was responsible for forming the majority of lakes we find in North America, particularly those in the northern latitudes. Glaciers slowly moved across the landscape creating lakes by a variety of processes. Basins are created by active ice scouring that carves them out, dams composed of either of glacial debris or ice, or depressions that are left behind as the glacier retreats. Despite the slow pace associated with glacial activity, historically spectacular floods have occurred when glacial dams have failed. During the last ice age, ice dams across the Clarks Fork River in Montana formed glacial Lake Missoula. At its maximum filling, the lake was 2,000 feet deep and contained 480 cubic miles of water, which is comparable to Lake Erie and Ontario. The ice dams would fail catastrophically when they began to float, and the waters poured across western Washington and drained into the Columbia River Gorge. The estimated discharge from the greatest flood is approximately 9 cubic miles of water per hour, which is 450 times the maximum recorded for the Mississippi River. The resulting flood was of dramatic proportion and rushed through the Columbia gap in less than one week, scouring the Columbia River Gorge to its present day configuration. Rocks that originated from the Rocky Mountains can be found over 1000 feet above the present river level along the Columbia River in western Oregon (sources: Alt and Hyndman 1995).

On a much smaller spatial scale, ice is an important agent of change in many northern watersheds. Ice jam-induced floods at "ice-out time" in early spring can significantly modify channels and floodplains, and the plant and animal communities that inhabit them.

Natural Change Processes: Tectonic Activity



Lake formed by tectonic processes (Hutchinson 1957)

Figure 23

Tectonic activity has formed lakes and altered the course of rivers over long periods of geologic time associated with uplifting and over the short events associated with earthquake activity (Figure 23). Slow movements of the earth's crust have exposed the Florida peninsula which was once covered by the sea. Irregularities in the land

surface created by former ocean currents created basins that are now lakes, an example being Lake Okechobee. By a different tectonic process, the irregular tilting of fault blocks creates depressions such as the basin where Lake Tahoe is located. In contrast to these slower processes, movements of the earth's crust associated with earthquakes can form basins and domes over very short periods of time. The New Madrid Earthquake of 1811 formed several of the lake basins of Tennessee and Missouri while a dome reversed the flow of the Mississippi River for a short time before it cut a new course to the sea. Local subsidence along fault lines such as the San Andreas forms depressions that become lakes. Earthquakes can also cause landslides that dam rivers or alter their courses (sources: Hutchinson 1957).

Natural Change Processes: Volcanic eruption

Volcanic eruptions can alter watersheds with tremendous force and over time periods as brief as hours or minutes (Figure 24). New lake basins are formed while old ones fill in. Changes in local topography create new routes for water that result in mountain streams where they had not existed before. Lava flows can cross stream channels either damming them to form lakes or diverting flow towards a new course. On Mt. St. Helens, the eruption of 1980 resulted in huge mudslides that formed a dam resulting in a much-enlarged Spirit Lake. Extensive areas of upland forest were incinerated and/or buried, and numerous nearby streams and rivers underwent fish kills due to heavy sediment loads in the water, primarily due to deposited ash. The gradual recolonization of the upland areas and water bodies has provided an excellent laboratory for observing recovery.

Mt. Hood, one of several volcanic peaks in the Pacific Northwestern US.

Figure 24

Volcanic events have a dramatic impact on upland forests, by destroying and modifying existing vegetation and creating new substrate. Primary impacts of volcanoes on forests are caused by the mechanical destruction of vegetation by lava flows or pyroclastic flows and associated fires, debris avalanches that occur with partial collapse of a volcano, mudflows which often follow existing stream channels and can transport debris, burial from ash deposits, and blowdowns from shockwaves. Secondary impacts can include soil changes and even climate changes. The ash from the Krakatoa eruption of 1883 encircled the globe and limited sunlight penetration reducing growing seasons as far away as North America. The species of vegetation most affected and their recovery from a volcano are determined by their ability to survive the eruption, their distance from and characteristics of the eruption, and the time since the eruption occurred.

Human-Made Changes

Change through anthropogenic factors is often closely tied to, and interactive with, natural change. A common form of human influence on watershed change is that the same **type** of change may occur, but at a very different **magnitude** or **frequency** (Figure 25, next page). You will note in the following discussion of human-induced changes that many of the same effects on the ecosystem are evident, but at magnitudes or frequencies that watershed ecosystems have not become adapted to over time. As mentioned, when these intensified changes exceed certain

thresholds, recovery is no longer certain and significant loss of natural resources, goods and services can result, to the detriment of human and ecological communities alike.

Given that some change is natural, could human-induced changes really be that harmful, or would ecosystems simply adapt to our modifications? The capacity of the human race to adversely influence the natural environment is best illustrated by our influence on the rate of biological species extinctions. In 1999, a working group of the world's leading evolutionary biologists ranked the brief period of human presence on earth as among the top 4 sources of mass biological extinctions in the planet's history. Recovery from the previous mass extinction period did take place, but it required 10 million years to occur.

Figure 25

Figure 26

Human-induced changes (Figure 26) include those major agents of change listed at left, plus a large number of minor and indirect effects too numerous to include in this discussion. While many management measures to avoid, minimize or otherwise remediate human-made changes have been developed, these management remedies are covered in other Academy 2000 modules rather than here, due to module length.

Human-induced Change Processes: Modification of River Flow

Land uses such as urbanization, agriculture and timber harvest in watersheds change runoff and flow in significant indirect ways, but this section specifically addresses how river flow is modified directly when water is impounded or diverted (Figure 27). In many cases, impoundment and water withdrawal occur together with the result that

Grandfather Falls Dam, Wisconsin has had a visible effect on reducing flow volume and changing sediment characteristics downstream, with resultant changes in aquatic habitat quality.

Figure 27

flow amplitude is reduced, baseflow variation increases, temperature regime is altered, and mass transport of materials declines. When these things occur, overall connectivity between upstream and downstream reaches and between the river and its floodplain are compromised. This has a detrimental effect on biodiversity and ecological processes. These effects are significant across much of North America. Approximately 3,500,000 river miles were once free flowing; of this, 500,00 to 600,000 miles (14 to 17% of total) are now behind dams. 1,523 hydropower projects are currently operating under FERC license or exemption but approximately 60,000 dams are found in the United States (source: FERC). Although many of these dams are small they do have an impact on the flow regime of rivers and streams. Only 312 significant streams in the lower 48 States (0.4% of the total U.S. river mileage) are still free flowing and undeveloped in their entirety. None of the 15 large rivers in the continental United States (mean annual discharges > 350 m3/sec.) are unaffected by human impoundment and diversions.

Even where dams exist, they can often be operated in a manner to that more closely mimics natural flow regimes. For more on this topic, visit the Academy module ***Protecting Instream Flows: How Much Water Does a River Need?*** (http://www.epa.gov/watertrain/river); Although it is unlikely that it will be possible or desirable to operate a dam in a manner *entirely* consistent with a natural flow regime, measures can be taken to both stabilize base flows and ensure flows necessary to reconfigure channels and transport and exchange sediment. Lack of periodic high flows in the Colorado River's Grand Canyon justified a carefully planned "flushing flow" water release, designed to restore habitat types that had been affected by the altered sediment dynamics caused by the dam.

Flow regime, however, is not the only aspect of a river affected by dams. Dissolved oxygen, sediment transport and habitat are also affected.

Downstream temperature can also experience significant changes in response to dam operation. Reservoirs in temperate latitudes typically stratify as lakes do, with a warm surface epilimnion layer and a cold, dense hypolimnion in the depths. Dams that release surface water tend to increase annual temperature variation whereas dams that release deep water will tend to decrease annual temperature variation. Substantial biological consequences can result from altered temperature regimes and related changes in dissolved oxygen. Dams also act as sediment traps that limit downstream sediment delivery, with mixed effects on downstream habitat. In the arid Southwest, for example, non-native trout fisheries are now present at the base of dams that release cold clear water into river channels that were once filled with warm, sediment-laden water.

Human-induced Change Processes: Agriculture

Agricultural practices can affect watersheds through several different means (Figure 28). Primary changes of concern result from streamside vegetation removal and soil tillage, application of fertilizers and pesticides and their subsequent export into water, grazing practices that can shift grassland vegetation to dominance by inedible species, and irrigation practices that dewater streams to levels that harm aquatic communities.

The clearing of forested watersheds for crop and pasture lands has often resulted in degraded water quality and modification of natural flow regimes (i.e., increased erosion, turbidity, fluctuations in discharge and temperature), compounded by such practices as soil tillage and application of fertilizers and pesticides. Under agricultural development, crops generally represent sparser ground cover than indigenous vegetation, allowing greater erosion and soil loss. Lands are ploughed and smoothed to create planting surfaces, while use of heavy machinery for tilling and threshing compacts soil. In temperate watersheds, soils are often ploughed in fall for spring planting, and are left bare throughout the winter and spring months during peak flow season, a practice which makes for increased runoff and vulnerability to surface erosion. Of the approximately 650,000 tons of suspended sediment delivered annually to the Great Lakes from agricultural watersheds, an estimated 0-30% are from bank erosion and 70-100% are from cropland and sheet erosion (Wall et al. 1982).

Before (left) and after instituting agricultural management practices to minimize stream damage at a Pennsylvania farm.

Figure 28

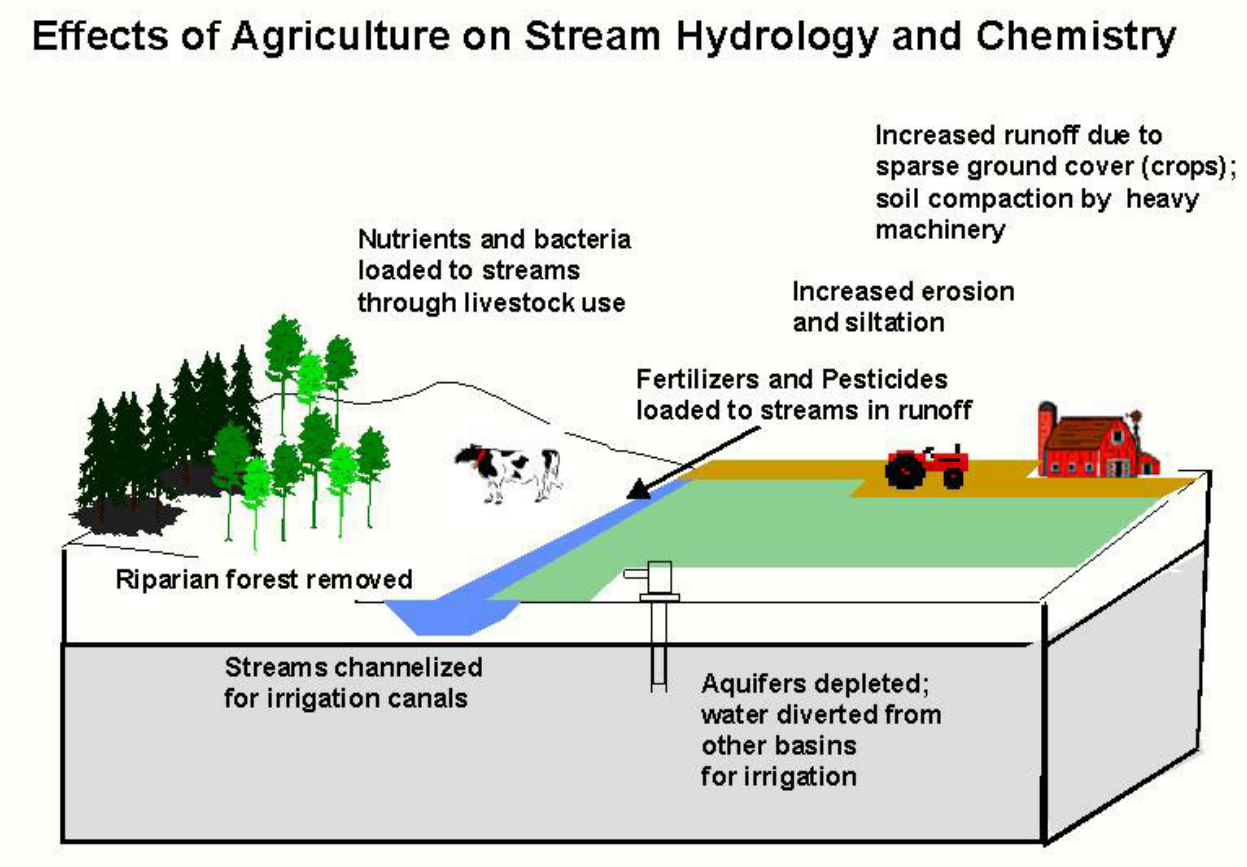

Effects of Agriculture on Stream Hydrology and Chemistry
Increased runoff due to sparse ground cover (crops); soil compaction by heavy machinery
Nutrients and bacteria loaded to streams through livestock use
Increased erosion and siltation
Fertilizers and Pesticides loaded to streams in runoff
Riparian forest removed
Streams channelized for irrigation canals
Aquifers depleted; water diverted from other basins for irrigation

Figure 29

In addition to altered hydrologic regimes, streams through agricultural lands typically feature high exports of dissolved nutrients (e.g., NO3, PO4) as a result of fertilizer applications and loss of forest cover (Figure 29). A typical result in agricultural streams and lakes is increased primary production (i.e., eutrophication) and depletion of dissolved oxygen as excess organic matter decomposes. Organochlorine compounds associated with pesticide use are also found in some agricultural waters. Although pesticides typically occur during a limited spray season, some compounds persist long enough in soils to load continually throughout the year via suspended sediments in surface runoff. In many cases, toxic effects may persist for several years after pesticide use has stopped. The pesticide DDT, for example, was banned in 1972 for most uses in the United States, but it continues to be found in trace amounts in soil, sediment, and tissue samples from agricultural watersheds across North America.

In some areas of the United States, particularly in the arid and semi-arid lands of the West, livestock grazing with unlimited access to the stream channel and banks can cause degraded water quality and is one of the most significant rural sources of non-industrial pollution (Figure 30). Although they often make up a small percentage of grazing areas by surface area, riparian zones (vegetated stream corridors) are particularly attractive to cattle that prefer the cooler environment and lush vegetation found alongside rivers and streams. This can result in increased sediment and debris input into streams due to "hoof shear," trampling of bank vegetation, downcutting by the destabilized stream with resultant drop in the water table, loss of fisheries, and direct deposition of wastes into waterways. Ironically, despite livestock's preference for frequent water access, farm veterinarians have reported that cows whose stream access is limited are healthier.

A field crew measures downcutting by a creek whose banks were trampled and destabilized by cattle. A lowered water table has reduced forage grasses in the adjacent pastures. Resident trout populations have also vanished.

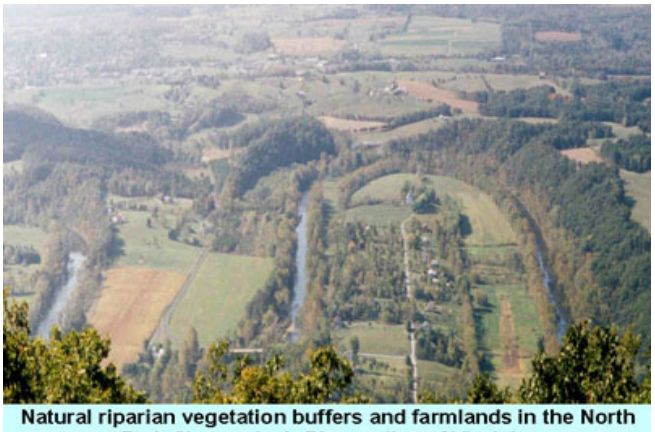
Figure 30

Irrigation of agricultural fields has had dramatic impacts on watershed hydrology through the diversion and detention of running waters and overutilization of groundwater reserves (Figure 31). In many cases, impacts are felt over broad regions encompassing several watersheds. Agriculture represents the heaviest demand for water in most parts of the United States, and accounts for more than 2/3 of global water use, but irrigation is a largely inefficient process, and less than half of all diverted water actually reaches the intended crops. Much of this loss is due to evaporation from reservoirs and seepage from canals. Because there is not widespread awareness of this loss, and because different political bodies have jurisdiction over parts of what is really a connected system, water rights for many river basins are oversubscribed. The Colorado River, for example, flows through seven U.S. states and Mexico, and these jurisdictions together have legal rights to withdraw more water annually than the river actually contains.

Pivot irrigation (left) in a subhumid climatic region loses water to evaporation; drip irrigation (right) is water-efficient, but still risks overusing groundwater reserves in some areas.

Figure 31

There are countless opportunities for reducing the adverse effects on aquatic systems from agriculture and grazing by following well-documented and publicized Best Management Practices (BMPs). Probably the best-known and most widely useful category of BMP is the retention of naturally vegetated buffer strips along streams (Figure 32). Streamside buffers serve many functions including nutrient filtering, bank stabilization, reduction of soil loss and land loss, moderating water temperature (which helps dissolved oxygen and hence fisheries), and terrestrial wildlife habitat and corridors for movement. Two challenges -- informing everyone who might be able to use BMPs, and overcoming resistance to changing established habits -- face watershed managers who hope to improve water quality in agricultural areas. CORE-4, a targeted public information program designed for the farmer and rancher, is a national outreach effort of the US Department of Agriculture's Conservation Technology Information Center, which promotes the four best practices to minimize agricultural impacts on water quality: buffers, conservation tillage, crop nutrient management, and weed and pest management.



Natural riparian vegetation buffers and farmlands in the North Fork Shenandoah River valley of Virginia.

Figure 32

Human-induced Change Processes: Timber Harvest

Many watershed effects of timber harvest are similar to agriculture's effects (Figure 33). Aquatic impacts such as altered runoff and streamflow, increased sedimentation, and addition of nutrients can result from silvicultural operations. The most obvious terrestrial change associated with timber harvest is that of removal of vegetation, but other common changes involve habitat alteration, altered species diversity and stand age. There are also numerous indirect effects.

Large clearcuts in the Oregon Cascades comprise a greater proportion than forests of the landscape visible here.

Figure 33

Under commercial forestry, mature, multi-aged, mixed-species forests are often replaced with young monoculture stands of commercially valuable species. In many cases, harvested lands are left denuded of live vegetation for long periods of time. These changes in forest habitat have different effects on different species. Species which rely on old-growth conditions for parts of their life cycle (e.g., northern spotted owl) may be adversely impacted, whereas species which use edge habitats (e.g., white-tailed deer) may increase in population. Intensity of disturbance generally corresponds with the spatial scale of the area cut, whereas rotation lengths control frequency. Accordingly, there is a distinction to be made between clearcutting (Figure 34), in which all trees harvested from a given area and replaced with an even-aged stand, and selective harvesting (i.e., some trees removed, others remain, resulting in a mixed-age stand). Whereas clearcutting results in drastic change over large areas of forest habitat, selective cutting may also produce significant impacts, as rotation lengths are typically shorter, and sites are therefore disturbed more frequently.

A Cascades clear cut within the first few years of regrowth after timber harvest.

Figure 34

In addition to terrestrial impacts, timber harvesting may have significant effects on stream discharge and water quality. Loss of mature vegetative cover leads to decreased evapotranspiration and correspondingly increased peak flows. These effects are compounded by road construction, which creates permanently bare surfaces and compacts soil, resulting in decreased infiltration and increased surface runoff (Figure 35). Logging roads also fragment and isolate habitat patches from smaller, less mobile animals such as salamander species, and roads' stream crossings and culverts sometimes become barriers to fish passage. Surface runoff on or near logging roads effectively increases stream density in logged watersheds, resulting in more rapid drainage and higher fluctuations between peak flows and base flow. Increased surface runoff, along with fewer trees for bank stabilization, generally causes increased erosion and siltation, while road construction on steep slopes often results in slope failure and excess sediment delivery to streams (Figure 36). Overall effects can also include elevated and more variable water temperature, increased turbidity, and higher uniformity of substrates, which generally impair habitat for a number of fish and invertebrate species.

Many watershed and water quality impacts associated with timber harvest arise in connection with roads built to transport the lumber.

Figure 35

This improperly sited and maintained logging road has eroded badly and essentially functions as a new intermittent stream. Drainage ditches of properly maintained roads also can increase stream density and reduce groundwater recharge.

Figure 36

Riparian buffers are required in many jurisdictions, but these have not always been successful in mitigating effects on streams. In general, it should be recognized that the effects of logging on stream discharge and temperature are caused by watershed-level processes and, as such, are unlikely to be completely mitigated by riparian buffers alone. *(Harr 1986, Murphy 1995, Jones and Grant 1996)* A major change in federal land management policy in the 1990s has begun integrating watershed analysis into timber management and multi-purpose land management on federal lands across the US.

Human-induced Change Processes: Urbanization

Urbanization often has more severe hydrologic effects than timber harvesting or agriculture, as watershed vegetation is replaced with impervious surfaces in the form of paved roads and parking lots. Accordingly, urbanization results in increased surface runoff and correspondingly earlier and higher peak flows following storms, as plotted on a hydrograph (Figure 37). Flooding frequency is also increased. These effects are compounded by channelization of small streams and use of storm sewers designed for rapid downstream transport of drainage waters, both of which are intended as flood control measures but in fact can contribute to rapid water rise and flooding downstream, often still within the urban area. There is a direct relationship between urbanization (i.e. % watershed imperviousness) and the number of bankfull flows occurring annually (Leopold 1968). It has been estimated that a watershed with 25% impervious surfaces is subjected once every five years to an event of peak volume equivalent to the 100-year storm under completely forested conditions. At 38% imperviousness, this same event occurs every 2.5 years, and at 65% imperviousness it occurs annually (Klein 1979).

Lake Union's watershed in Seattle, WA has become heavily urbanized and faces many management challenges related to the effects of urban impervious surfaces

Figure 37

Bank scour from frequent high flow events tends to enlarge urban streams and result in increased turbidity and uniformity of substrates. Structural complexity is then further reduced by bank armoring, and channelization designed to limit the damage to streamside property resulting from increased flooding and erosion (Figure 38). In many cases, however, channelization results in increased flow velocities and subsequently increased flooding and erosive power downstream.

Urban channelized and "hardened" streams (left) are poor habitat but route stormflows quickly. Natural streams below urban areas (right) retain some habitat features but become heavily eroded by flows from increased urban runoff.

Figure 38

These physical impacts of urbanization are compounded by contaminant inputs from a variety of sources. Urban contaminants may be loaded directly to streams and lakes (Figure 39, next page) from point sources (e.g., sewage, industrial effluents), or they may originate from nonpoint sources (e.g., atmospheric deposition and/or street litter washed off impervious surfaces and incorporated in storm runoff). Individual nonpoint source loadings are generally of small volumes, but these tend to be ubiquitous in urban watersheds and collectively represent an important contribution to overall pollution. Whereas

quantification of point source pollution is relatively straightforward, assessment and control of nonpoint source loadings are made difficult by the fact that contaminants originate over broad areas and the processes by which they are carried are often not easily modeled or measured.

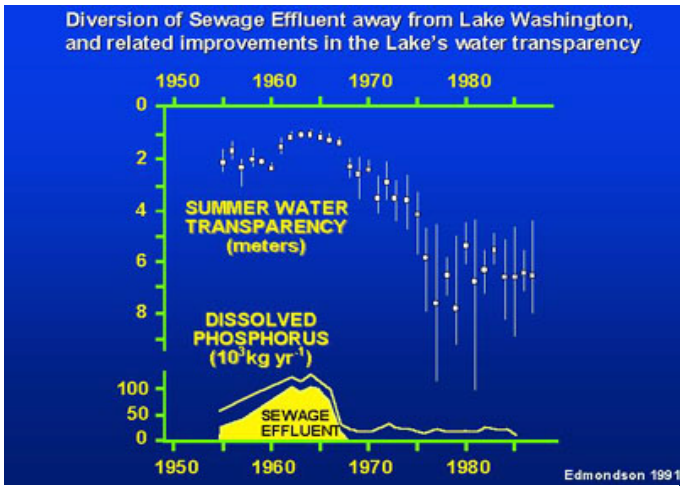


Figure 39

As a result of these effects, a direct inverse relationship may be demonstrated between the diversity of stream communities and the degree of urbanization. Klein (1979) reported reduced fish and invertebrate diversity at 12% watershed imperviousness (10% for areas supporting self-sustaining salmonid populations), and severe degradation in the form of reduced benthic populations and absence of fish life at 30% imperviousness. The presence of an intact riparian buffer and/or wetlands, which unfortunately have not been conserved in most urbanized areas, can lessen these impacts.

In many cases, the effects of urbanization extend far beyond the urbanized watershed. As urban growth increases, water must be pumped in from increasingly great distances to meet sewage and drinking water requirements of urban populations. For example, pumping water from the Sacramento and Colorado Rivers over hundreds of miles and hundreds of feet in elevation in aqueducts and canals facilitated the growth of urban centers in southern California. These diversions and impoundments have resulted in widespread hydrologic and ecological changes, as well as significant economic and political conflicts (Reisner 1986).

Human-induced Change Processes: Fire Suppression

In the years following European settlement, forest management policies related to fire suppression have had a profound impact on forest community structure (Figure 40). Since the turn of the century, suppression has been the primary goal of fire policy in mixed conifer forests of the Pacific Northwest, the overall effects of which have been an increase in fuel accumulation and a shift in composition toward shade-tolerant species and away from fire-dependent conifers (Huff et al. 1995, Kimmins 1997). Effects have generally been more profound in areas where fires were historically frequent as opposed to where fires occurred at longer return intervals.

An airplane releases fire retardant chemicals to suppress an active forest fire.

Figure 40

These changes increase potential for high-intensity crown fires, not only by providing more available energy but also by creating pathways for flames to reach the forest canopy. Such crown fires usually exceed our control and kill all species present, including those resistant to fires of moderate to low intensities. For example, fuel buildup due to fire suppression is in part responsible for the catastrophic fires in 1988 that burned almost half of Yellowstone National Park. The accumulation of fuel is one of the biggest concerns of land managers today, who now fear that when fires occur they will be extremely difficult to control, although the implications of fire suppression extend beyond increased potential for catastrophic fires. Fire represents an important component of forest ecology, as fires increase the availability of soil nutrients, while periodic disturbance results in a mixture of seral stages and increased biodiversity. Recognizing this, forest managers in U.S. national parks have adopted a fire management policy that combines a let-burn approach with active monitoring and prescribed burns (Figure 41).

A forest manager carries out a prescribed burn using a drip torch.

Figure 41

In trying to determine the effects of fire or fire suppression on forest community composition, note that plant succession is not always predictable. In addition to variables such as many species' responses to disturbance or life history traits which affect patterns of vegetation change, random factors may come into play. This presents difficulties in determining whether or not fires should be suppressed on public lands. Such decisions are further complicated by the fact that forest conservation has become a management imperative to many, given the decline of forested lands in North America and worldwide. If forest fires are allowed to burn without intervention, entire regions may be deprived of forest resources for long periods of time. Long-term goals related to the preservation of ecological processes and relationships must therefore be weighed against shorter-term goals of resource use, aesthetics and recreation when local management decisions are made.

Human-induced Change Processes: Mining

Mining and mineral development result in a series of environmental changes which may occur over several decades. The actual mine site is just one point in a long line of activity before and after the digging starts. A mine is also at the center of a geographical web of transportation routes (e.g., roads, barges, air access routes) and energy infrastructure (e.g., dams, power lines), as well as processing plants, tailings ponds and waste rock piles. The basic stages of mineral development are: (1) preliminary and advanced exploration, (2) mining and milling, (3) smelting and refining, and (4) mine closure. Each of these stages entails specific activities and environmental impacts. Activities and impacts also vary with different mining procedures and environmental settings. Historically before more recent environmental controls, mining left a legacy of severe impacts on watersheds and the rivers and streams of western federal lands, as

well as in eastern coal mining areas. Restoration after mining remains a significant challenge in many parts of the US.

Mining operations remove significant amounts of soil and rock. The Bingham Canyon copper mine in Utah has removed a piece of earth seven times the weight of all the material dug for the Panama Canal (Goudie 1990). Worldwide, mining operations extract approximately 24 billion tons of non-fuel minerals from the Earth each year. Taking into account overburden (soil and rock above the ore), the total is 28 billion tons of material disturbed annually. This amounts to approximately 1.7 times the estimated amount of sediment carried by all of the world's rivers each year (Skinner 1989). Even if chemically inert, erosion of exposed overburden can result in excessive siltation affecting stream and lake ecosystems (Figure 42).

Without proper restoration, mining can have severe impacts upon stream hydrology, morphology, biota and water quality.

Figure 42

After being removed, waste rock is usually stored above ground in freestanding piles. When rocks containing sulfide minerals are excavated, they react with water and oxygen to form sulfuric acid. The resulting leachate is known as acid mine drainage (AMD). AMD will continue to be produced in source rock exposed to air and water until all of the sulfides are leached out, a process that can last hundreds and even thousands of years. During this process, there is a constant risk of water pollution, as AMD is transported from mine sites in surface drainage to receiving streams, lakes and groundwater.

Further effects stem from extraction of the ore itself and from disposal of tailings (i.e., residues from ore concentration). Up to 90 percent of metal ore ends up as tailings, which are commonly dumped in large piles or ponds near the mine. Tailings usually contain residues of toxic organic chemicals used in ore concentrators (e.g., toluene, a solvent damaging to human respiratory, circulatory and nervous systems). The finely ground tailings material makes metals that were formerly bound up in solid rock (e.g., arsenic, cadmium, copper, lead and zinc) accessible to water, increasing potential for heavy metal contamination in aquatic communities. These effects are exacerbated by AMD, which creates low pH conditions, thereby increasing the mobility of many heavy metal species. Ponds full of tailings cover at least 3500 hectares in the Clark Fork area of Montana, and 2100 hectares at the Bingham Canyon copper mine in Utah (Young 1992).

Smelting can produce significant quantities of air pollutants. Worldwide, smelting of copper and other non-ferrous metals releases large quantities of metals such as As, Pb and Cd, as well as an estimated 6 million tons of sulfur dioxide into the atmosphere each year. Smelting produces approximately 8 percent of total emissions of the sulfur compound that is a primary cause of acid rain (Moller 1984), well-known in the Northeastern US for its heavy impacts upon the fish and invertebrate populations of headwaters streams and lakes (Figure 43). Mining and smelting operations also consume significant amounts of energy. Although data are sparse, the mineral industry probably accounts for 5 - 10 percent of global energy use (Young 1992).

Although Brook Trout are more tolerant of low pH than most salmonids, they have still been heavily impacted by acid mine drainage and aerial acid deposition in the Northeastern US and the Appalachians.

Figure 43

Human-induced Change Processes: Harvesting of Fish and Wildlife

Commercial and recreational harvesting of fish and wildlife may have significant impacts on community composition and trophic (food web) interactions, well beyond the removal of the target species (Figure 44). These effects have been most pronounced in commercial fisheries, where harvest pressures have resulted in a gradual shift from large, long-lived, high trophic level species to smaller, shorter-lived, planktivorous and insectivorous species. Recent studies have reported a steady mean decline of approximately 0.1 trophic levels per decade in worldwide catches over the past 45 years. These changes in decreased abundance of one trophic level lead to trophic cascades where perturbations at higher trophic levels cascade down to lower trophic levels. This is because piscivores determine the size and species composition of planktivorous fish, which in turn affect the zooplankton community composition, that determines the kinds of phytoplankton that compete for nutrients (Carpenter and Kitchell 1993).

Figure 44

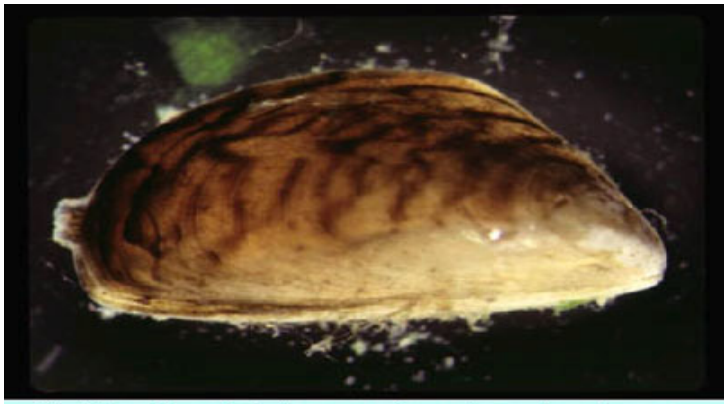
Placing a moratorium on certain species such as the striped bass in the Chesapeake Bay (Figure 45, next page) is a management technique that has successfully brought about significant changes in numbers and sizes of fish, after a combination of overharvest and habitat decline pressures had seriously reduced populations of this game and recreational fish. Management techniques like the moratorium represent the kinds of sacrifices in natural resource use that can become necessary, in part, due to changes of concern in the watershed. Rebounding numbers of fish have occurred simultaneously with increases in submerged vegetation beds, a key habitat

Figure 45

whose decline and subsequent resurgence was related to several aspects of watershed management.

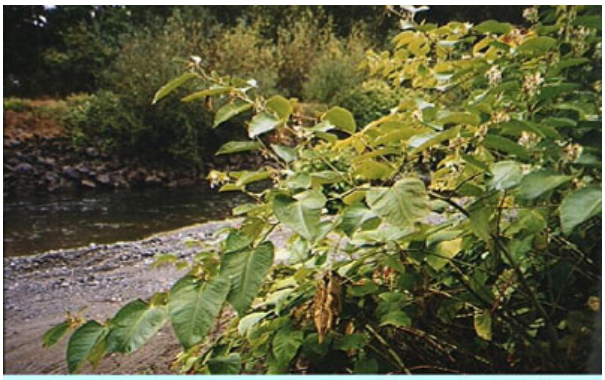
Human-induced Change Processes: Introduction of Exotic Species

Human mobility has resulted in significant exchanges of biota, occurring at global and local scales. Exotic species, or invasive non-native species, may be introduced to a given region intentionally, as with ornamental plants or popular game fish species, but in many cases they are transported and introduced unintentionally. For example, zebra mussels have become abundant in the aquatic ecosystems of the Great Lakes, having been transported in ballast waters of large ships arriving from Europe, and are spreading rapidly to other systems (Figure 46). Once an invasive plant species is established near a river or stream (Figure 47) , the flowing water of streams and rivers and the contiguity of river corridors has helped many exotic species spread far and wide. Similarly, a study by Schmidt (1989) found viable seeds from 124 different plant species in sludge washed off the mudguards of a car that had driven approximately 15,000 km in the area surrounding Gottingen, Germany. These findings suggest that plants growing in roadside areas may be readily dispersed by moving vehicles. As human mobility increases as a result of extensive international trade and worldwide travel opportunities, more and more regions are likely to be affected by introductions of exotic species.



The Zebra Mussel, *Dreissena polymorpha*, an invasive non-native species significantly altering many US waters.

Figure 46



Japanese Knotweed, an invasive non-native species that forms dense monocultures and displaces native plants along stream and highway corridors across the US.

Figure 47

In some cases, introduced species do not prosper because they lack adaptations to local environments, but in many cases introduced plants and animals outcompete native species through prolific reproductive strategies and a lack of natural predators. Establishment of exotic species often results in significant changes in food webs and community composition. For example, introduced honeybees have had adverse impacts on indigenous flowering plants in Australia, South America and North America. Several studies have indicated that introduced honeybees outcompete native pollinators, but they may be ineffective in pollinating native flowers.

As a result, the reproductive success of native plants is hampered by reduced seed sets, and offspring are less vigorous due to reduced genetic diversity as a result of increased self-pollination (Kearns and Inouye 1997). Resulting changes in plant abundance and species composition may have further direct and indirect effects on herbivore and carnivore populations.

The effects of exotic species have been particularly devastating to the Great Lakes basin, which is a site of several invasions and a source for the spread of invaders across North America. The Great Lakes are now inhabited by at least 139 nonindigenous species that have been transported by human activity. These reported exotics are mostly fish, vascular plants and some of the larger (> 0.5 mm) plankton species. Intensive management efforts have been directed toward controlling the most pervasive and visible exotics (e.g. sea lamprey), although it is likely that many smaller exotics exist for which the taxonomy is less well known. Some exotic species have had significant effects on Great Lakes ecosystems. For example, recent changes in the trophic status of Lake Erie (i.e., shift from eutrophic to mesotrophic conditions) have been attributed in part to the introduction of filter feeding zebra mussels. With each individual capable of filtering 10 - 100 ml of water per hour, zebra mussels may be highly effective in removing phosphorus and other aquatic contaminants from the water column (Mackie and Wright 1994). These seemingly positive effects, however, are counterbalanced by the displacement of native filter feeders that are better integrated into the ecosystem's food webs and natural processes.

Exotics are thought to have been involved in 70% of this century's extinctions of native aquatic species. The U.S. Fish and Wildlife Service declared invasive exotic species control one of their top four priorities for 1999 and beyond; futhermore, 500 scientists signed a letter to the Vice President asking to make control of aquatic nuisance species a priority program. For more information on this subject, see the Academy module on invasive non-native species (http://www.epa.gov/watertrain/invasive.html).

Human-induced Change Processes: Accelerated Climate Change

A major difference between natural and anthropogenic climate change is the rate at which it occurs (Figure 48). With industrialization and population growth proceeding at a rapid pace over the last century, greenhouse gases from human activities have consistently increased in the atmosphere. Although it is not the only greenhouse gas, CO_2 clearly illustrates the trend where levels since 1860 have increased from 280 ppm to 360 ppm. Measurements from ice cores extending back 160,000 years show that CO_2 levels and global temperature are strongly correlated. If current emissions trends continue, CO_2 and temperature will rise to their highest levels in the past 50 million years. Current predictions indicate that we

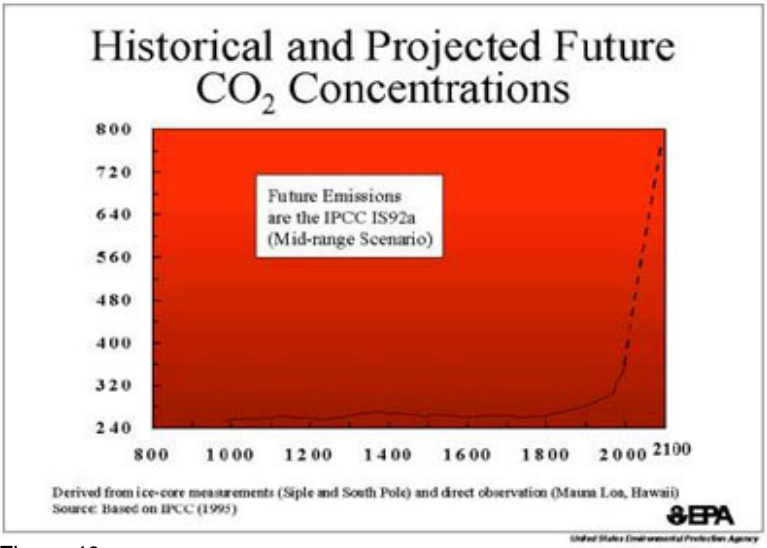


Figure 48

can expect an increase of 3.5°F over the next century with this continued release of CO_2 into the atmosphere.

Over the last century the average surface temperature of the earth has warmed by approximately 1.0°F (Figure 49). The higher latitudes have warmed more than equatorial regions. These changes may seem small and some have argued that over geologic time our planet has experienced changes in global temperature (during the Cretaceous period temperature is estimated to have been 8.5°F higher than at present).

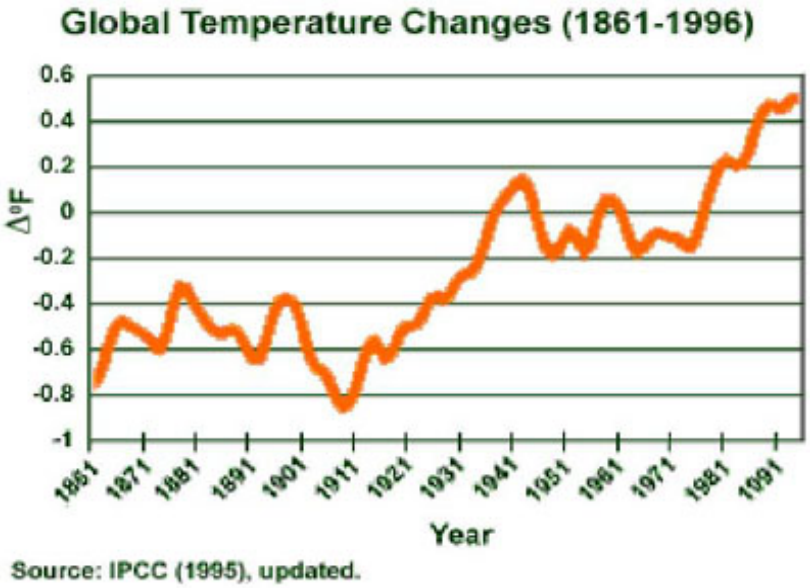


Figure 49

Despite these apparently small increases in temperature, however, we can expect major impacts on the global hydrologic cycle and other natural processes (Figure 50). When air temperature increases just 1°F, the air can hold 6% more water. This warming trend tends to speed up the exchange of water among oceans, land, and atmosphere. Longer droughts punctuated by heavy bursts of rain and flash flooding are a consequence. These effects can determine the water supply available to plants and the hydrologic regime of streams and rivers. Species composition of upland plant communities will also undergo major changes. For more information on climate change, visit the EPA website on Global Warming (http://www.epa.gov/globalwarming).

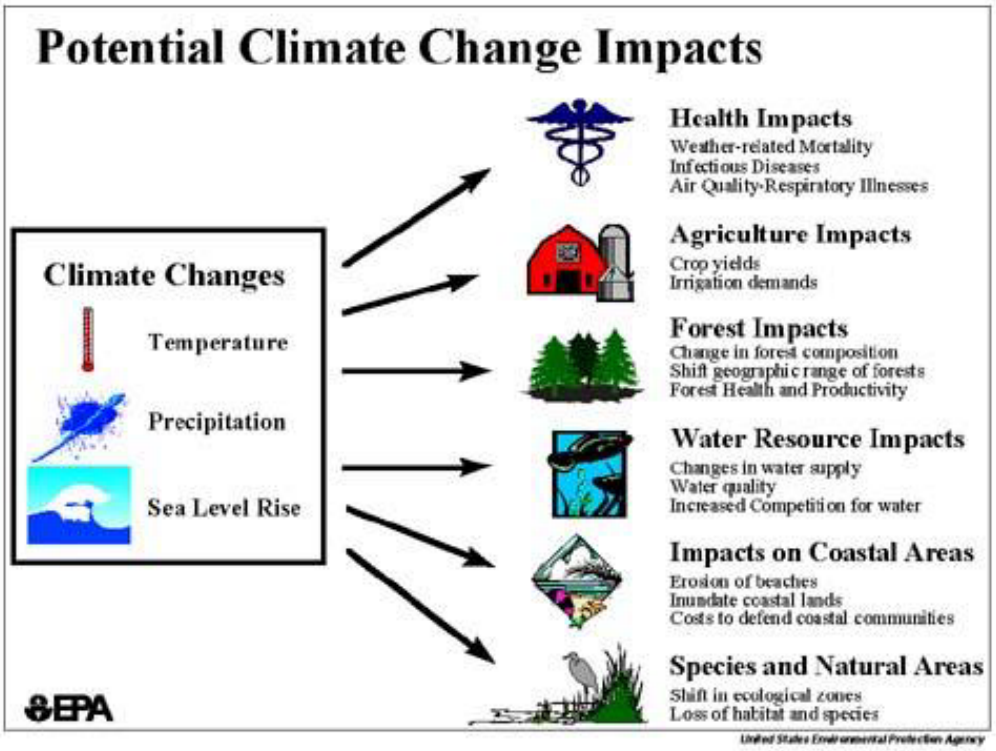


Figure 50

How Change Affects Watershed Processes

In many cases, watershed change occurs as a result of several agents of change that act together (Figure 51). Changes of concern often result from interactions of natural and human-induced disturbances. Even where individual stresses are relatively insignificant, ecological processes and relationships may be significantly influenced by the cumulative impacts of multiple stresses. Change is also not a single-step phenomenon, in that the original disturbance may lead first to direct effects that then bring about additional indirect effects (Figure 52, next page).

Figure 51

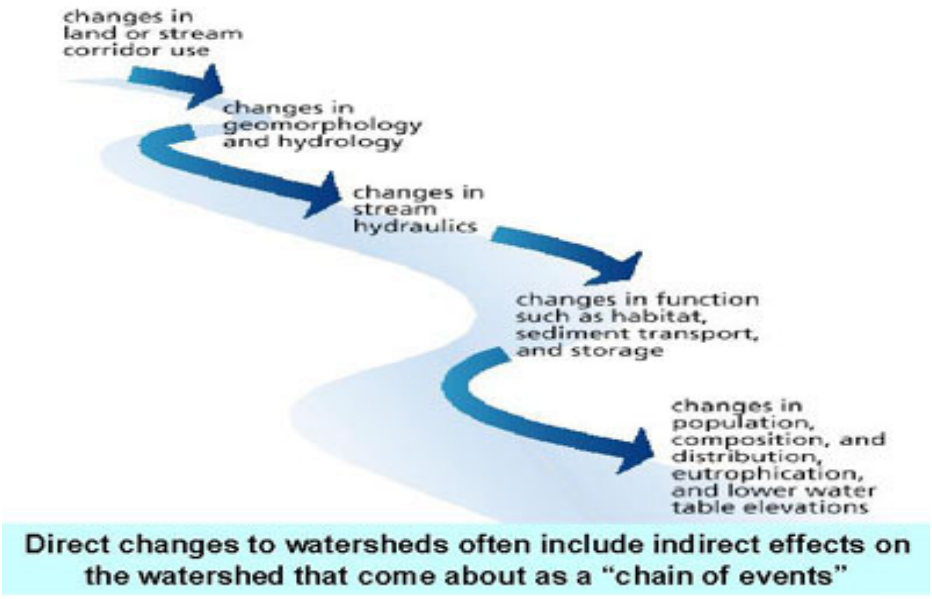

changes in land or stream corridor use
changes in geomorphology and hydrology
changes in stream hydraulics
changes in function such as habitat, sediment transport, and storage
changes in population, composition, and distribution, eutrophication, and lower water table elevations
Direct changes to watersheds often include indirect effects on the watershed that come about as a "chain of events"

Figure 52

For example, overall reproductive success of Pacific salmon populations may be significantly affected by the cumulative impacts of relatively minor stresses at various life history stages (Figure 53). Under average environmental conditions (e.g., gravel size, flow, temperature), and in the absence of human influences, survival rates may be as low as 10% for incubating pink salmon eggs, even in relatively productive streams (Groot and Margolis 1991). Of those eggs which survive to emergence, as few as 1% may survive juvenile and smolt stages, oceanic life and upstream migration to spawn successfully themselves (i.e., total survival on the order of 1/1,000). Given that the average pink female lays approximately 2,000 eggs, some populations may only just replace themselves with each subsequent generation. Accordingly, these populations may decline rapidly or even become extinct as a result of relatively small increases in mortality at different life history stages due to various anthropogenic stresses (e.g., increased peak flows and bed scour during winter egg incubation, increased commercial harvests at sea, or physical barriers to upstream migration and spawning).

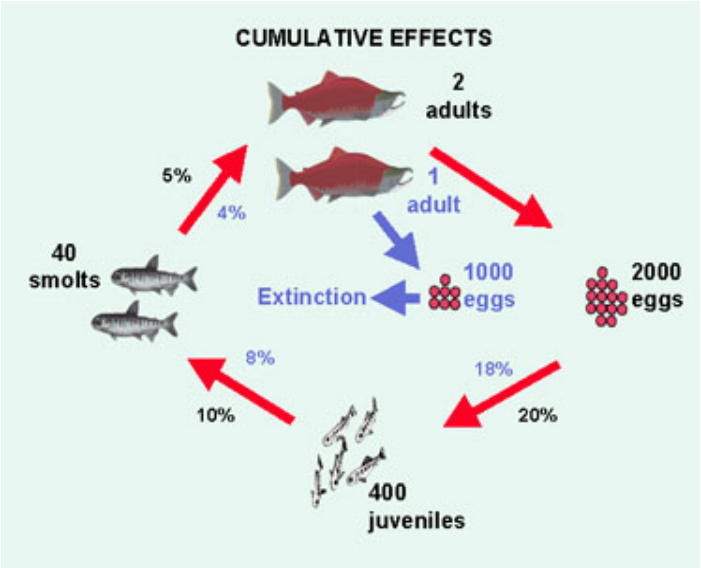


Figure 53

In addition to cumulative impacts, significant change may occur as a result of the **interactive effects** of different agents of change (Figure 54)). Two or more agents of change acting together may produce more severe or entirely different impacts than would result from each change in itself. For example, climatic changes typically entail changes in disturbance regime (e.g., fire frequency) which may alter plant species composition. Another example of interactive change is the way metals toxicity in lakes may result from changes in pH due to acid precipitation. Metals behave differently at different pH levels. At specific critical pH levels (pHzpc) different metals become less soluble and precipitate out of the water column, and become available to the aquatic food web. Aluminum (Al) for example has a pHzpc of approximately 5.3. In areas with high concentrations of Al in underlying substrates, or where Al is a constituent of urban and industrial pollution, fish may be more likely to die of Al toxicity than acid toxicity as pH values decrease and approach a pH of 5.3.

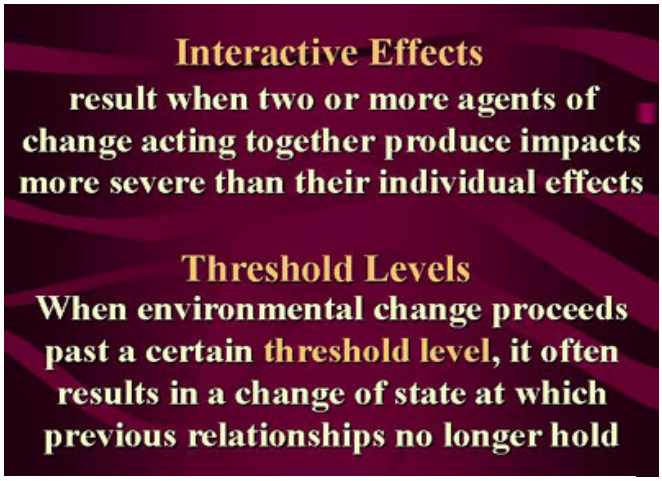

Interactive Effects
result when two or more agents of change acting together produce impacts more severe than their individual effects
Threshold Levels
When environmental change proceeds past a certain threshold level, it often results in a change of state at which previous relationships no longer hold

Figure 54

Another important concept is that of **threshold levels** of change. When environmental change proceeds past a certain threshold level, it often results in a change of state at which previous relationships no longer hold and entirely new influences come to bear on ecological communities. For example, microbial activity generally increases with temperature, but will drop off due to increased mortality once temperatures reach a given threshold. Similarly, increased algal productivity may result in increased productivity in zooplankton and planktivorous fishes in lakes, but this relationship ends at a certain threshold level of algal production. When a superabundance of algal cells die and decompose before they can be eaten by zooplanktors, resulting increases in oxygen demand may entail decreased productivity at higher trophic levels. This common eutrophication scenario may result in rapid declines in populations of fishes with high oxygen requirements (e.g., salmonids), particularly when lakes are stratified and deep-water oxygen inputs are minimal.

As you may have noticed while reading the summaries of different change agents and their effects, some watershed processes are particularly vulnerable to change (Figure 55). Four major watershed processes and the ways in which they are influenced by the cumulative and interactive effects of multiple stresses are reviewed in the coming pages. The processes are:

Figure 55

- Hydrology
- Sediment Transport
- Nutrient Cycling
- Trophic Interactions/Competition

Hydrology

Land use practices such as forestry, agriculture and urbanization affect amounts and rates of evapotranspiration, infiltration and surface runoff within the watershed, which in turn have significant impacts on the timing and magnitude of stream discharge events (Figure 56). As discussed, the general hydrologic symptoms of forest clearing, agriculture and urbanization are increased peak flows and decreased base flows, resulting in more frequent flooding, increased bank erosion and siltation, and other effects (Figure 57, next page). These effects are often exacerbated by measures designed to mitigate flooding and erosion (e.g., culverts, bank armoring, channelization of streams), which further increase drainage efficiency and flow velocities, resulting in increased flooding and erosion downstream. As a result, urban and logged streams tend to be wider, warmer and more turbid than their forested counterparts, and floods and spates tend to occur more frequently at intensities beyond the abilities of fish and invertebrate communities to adapt.

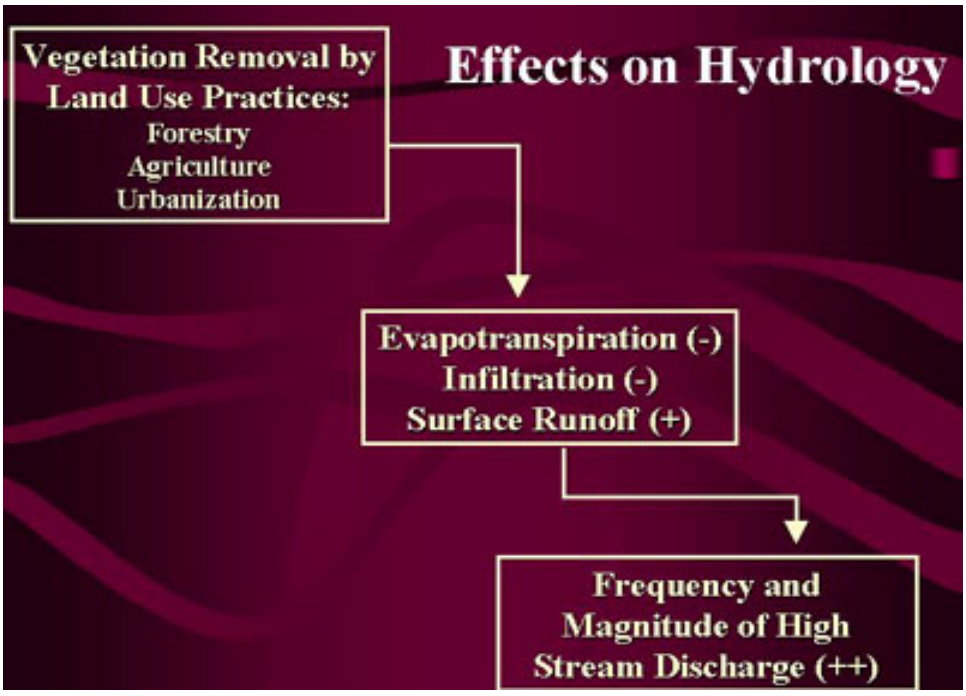


Figure 56

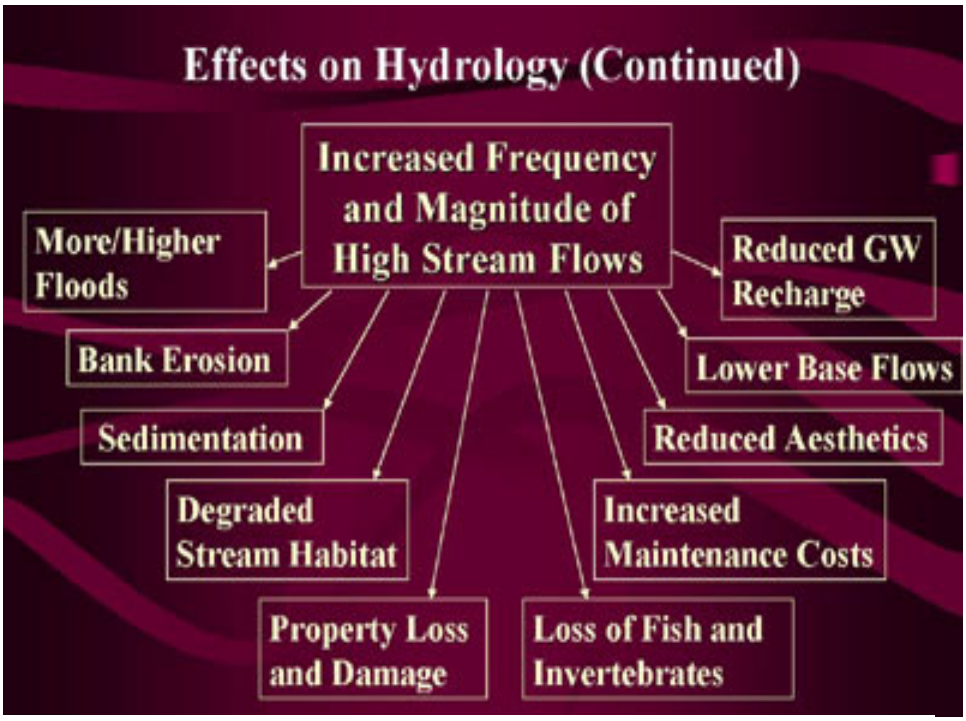


Figure 57

Sediment Transport

Erosion and sedimentation typically increase as a consequence of the hydrologic impacts of land use practices (Figure 58). Streams and lakes in urbanized, agricultural and logged watersheds are therefore characterized by increased levels of turbidity, relatively uniform substrates and high proportions of fine particles. These conditions may be detrimental to aquatic life in themselves: For example, suspended sediments can clog the gills of fish, while increased fines in spawning beds impede water flow and hamper oxygenation of incubating salmon eggs. Increased sedimentation may also have indirect and/or interactive effects, such as increased contaminant loadings. Human land uses tend to produce organic contaminants (e.g., petroleum byproducts, pesticides, industrial solvents), which are highly sorptive and partition strongly to fine particles with high ratios of surface area to volume. Increased siltation may therefore result in increased contaminant loadings and correspondingly increased toxic effects in impacted watersheds.

Figure 58

Conversely, dams and other modifications of river flow may decrease sediment delivery, which create large reservoirs where suspended materials settle easily. Inordinate reductions in

sedimentation may also have detrimental impacts on aquatic life downstream of dams. Moreover, lack of sediment loads may result in carrying less sediment and correspondingly increased erosive potential downstream (i.e., a river unencumbered by sediment loads will have a greater capacity to pick up and move materials). As a result, areas downstream of large reservoirs may be scoured to create bedrock channels or armored substrates offering little structural habitat for aquatic life.

Nutrient Cycling

Human activities tend to remove nutrients from soils (e.g., in form of agricultural crops, timber harvested) to be transported to cities and towns (e.g., in form of food, wood products) and ultimately loaded to aquatic systems in other watersheds (e.g., in form of municipal sewage). At one end of this process, soil nutrient cycles are disrupted by loss of detritus and litter pools (Figure 59). At the other end, nutrient cycling and trophic interactions in rivers and lakes are altered by excess nutrient inputs. Productivity in freshwater systems is often limited by phosphorus, but in some cases nitrogen. Municipal sewage generally contains high amounts of both NO_3 and PO_4, which may stimulate algal productivity to the point where other organisms are affected by oxygen depletion (Edmondson 1991). Depletion of nutrients from agricultural soils often necessitates addition of fertilizers, which are often easily washed off fields to receiving waterbodies, exacerbating eutrophication effects. The annual replacement cost, in fertilizer, for nutrients discarded in U.S. sewage has been calculated at almost $1 billion (Shaeffer and Stevens 1983).

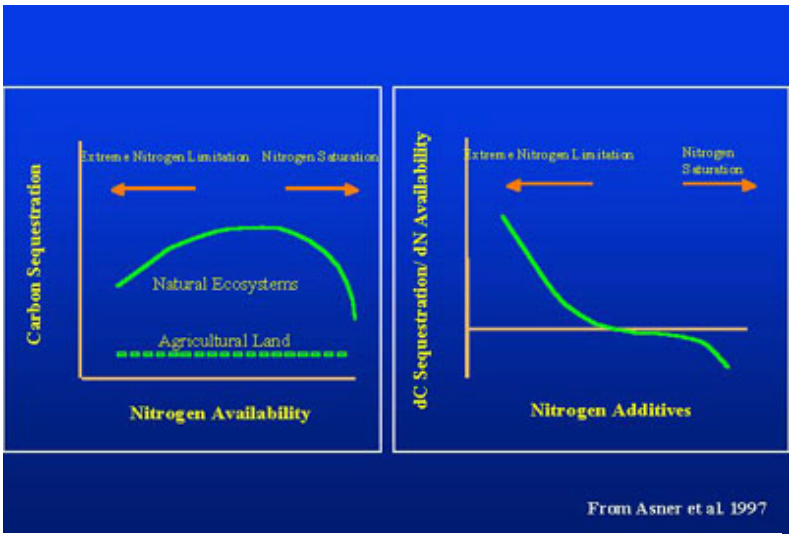


Figure 59

Over the past century, inputs of nitrogen to the Earth's atmosphere, soils and aquatic ecosystems have doubled as a result of the cumulative impacts of human activities (Vitousek et al. 1997). The combustion of fossil fuels results in atmospheric emissions of N_2O, an important greenhouse gas, as well other oxides of nitrogen (e.g., NO) which drive the formation of photochemical smog. Inputs to soils have been as a result of fertilizer applications and increased atmospheric deposition, while freshwater ecosystems have been affected by runoff from nitrogen-enriched soils, as well as direct inputs (e.g., sewage). As NH4 builds up in soils, it is increasingly converted to NO_3 by microbial activity. This process releases hydrogen ions and acidifies soil. As negatively charged NO_3 molecules leach out into streams and groundwater, they carry with them positively charged nutrients such as calcium, magnesium and potassium. In affected watersheds, acidification and loss of cations degrade soils, while aquatic communities are affected by eutrophication.

Trophic Interactions/Competition

Harvesting of fish and wildlife and introductions of exotic species have direct impacts on species composition, while habitat alterations (e.g., as a result of urbanization, timber harvest) have

indirect effects (Figure 60, next page). As different species are displaced, fragment or extirpated in response to habitat changes, new species expand to occupy niche vacancies. In general, anthropogenic influences favor generalist taxa capable of withstanding a wide range of environmental conditions, while populations of more sensitive or specialized taxa tend to decline. The cumulative effects of anthropogenic activities also tend to work against organisms of high trophic levels. While commercial fisheries eliminate top predators from the aquatic food web, these organisms are also affected by biomagnification of contaminants (i.e., concentrations of bioaccumulative contaminants are magnified by up to several orders of magnitude at each successive trophic level). Although concentrations of contaminants such as PCB's are so low in the Great Lakes that they can not be measured with standard water tests, they exponentially accumulate as they move up the food chain and are incorporated into animal tissue. Through this process the concentration of PCB's in a top predator can be 25 million times that of the surrounding water. In general, top predators are especially vulnerable to environmental change because they rely on all subordinate trophic levels for sustenance.

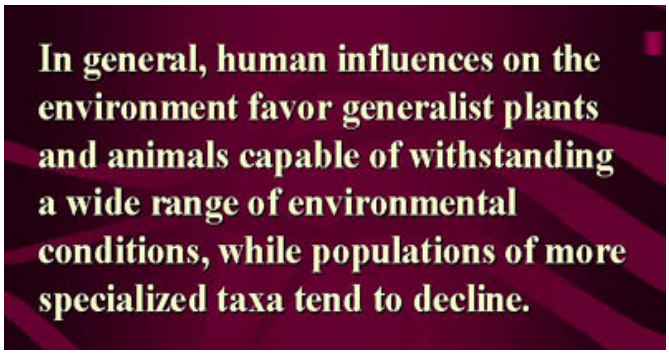

In general, human influences on the environment favor generalist plants and animals capable of withstanding a wide range of environmental conditions, while populations of more specialized taxa tend to decline.

Figure 60

Summary

Change is both unavoidable and essential in the watershed, as plant and animal communities are continually altered in response to changes in physiographic and climatic conditions (Figure 61). Environmental change or disturbance occurs at varying spatiotemporal scales. Disturbance processes are typically characterized according to the frequencies and intensities with which they occur. Changes of concern are defined as disturbances resulting in significant long-term alteration or loss of primary watershed processes or structural components.

Figure 61

Natural agents of change in the watershed discussed here include:

- climate change
- glacial movement
- tectonic activity

- volcanic eruption
- drought/flood
- fire
- windstorms
- erosion and sediment deposition
- disease outbreaks

Human-made agents of change in the watershed discussed here include:

- accelerated climate change
- timber harvest
- agriculture
- urbanization
- modification of river flow
- mining
- fire suppression
- harvesting of fish and wildlife
- introduction of exotic species
- air pollution

In many cases, watershed change occurs as a result of cumulative and interactive effects of more than one agent of change. Changes of concern often result from the interactions of natural and anthropogenic disturbances. These cumulative and interactive effects have resulted in widespread changes in watershed processes such as hydrology, sediment transport, nutrient cycling, and trophic interactions.

A self-test to assess your comprehension is included on page 44 of this module.

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Acknowledgments

The authors extend their thanks to technical reviewers Susan Bolton, Derek Booth, Don Garofalo, Robert Goo, and Doug Norton, and also appreciate the numerous contributions of photography and graphics used in this module provided by the Federal Interagency Stream Corridor Restoration Working Group, Doug Norton, Tom O'Keefe, and the US Forest Service.

SELF TEST FOR AGENTS OF WATERSHED CHANGE MODULE

After you've completed the quiz, check your answers with the ones provided on page 49 of this document. A passing grade is 14 of 20 correct, or 70%.

1. Which of the following is most accurate?

☐ A. Most human-made changes to watersheds are inevitable and cannot be controlled.

☐ B. Most human-made changes to watersheds could be controlled if we knew technical solutions for the problems they create.

☐ C. Most human-made changes to watersheds can be controlled but occur due to limited awareness of the remedies or willingness to use them.

☐ D. Most human-made changes to watersheds are not of concern.

2. Which of the following is most accurate?

☐ A. Watershed ecosystems don't change permanently from the influence of natural disturbances alone.

☐ B. Watershed ecosystems can be changed permanently by natural evolutionary events.

☐ C. Natural changes do cause adverse effects on some components of the ecosystem, while benefiting others.

☐ D. A and B

☐ E. B and C

☐ F. A and C

☐ G. All of the above

3. Grazing with unlimited access to all parts of a stream by livestock can create which of the following adverse impacts?

- ☐ A. Downcutting streams and eroding banks.
- ☐ B. Siltation in the streambed, nutrients and pathogens in the water.
- ☐ C. Degradation of fish populations.
- ☐ D. Lowering the water table
- ☐ E. Less healthy cattle
- ☐ F. None of the above
- ☐ G. A through C
- ☐ H. A through E

4. A change of concern is:

- ☐ A. Any change that takes a long time to recover, in terms of human life spans and time scales.
- ☐ B. Any change that involves human-made agents of change.
- ☐ C. Any change that results in the loss of a beneficial functional or structural characteristic of the watershed.
- ☐ D. Any change that results in a different type of ecosystem than what had been there before.

5. Cumulative impacts from multiple agents of change are potentially more of a challenge to watershed management because:

☐ A. watershed managers cannot do anything about natural impacts.

☐ B. different agents of change are contributing impacts at a variety of spatial and temporal scales.

☐ C. it is often difficult to identify the amount of adverse impact that comes from each agent of change, when planning a remedy.

☐ D. A and C

☐ E. B and C

☐ F. A and B

☐ G. A through C

☐ H. none of the above

6. For many changes of concern, there are known solutions but the awareness of the people responsible has been limited.

☐ A. True

☐ B. False

7. 100-year or larger floods are the primary force that determines what a stream channel is shaped like.

☐ A. True

☐ B. False

8. When native species can no longer survive, it is a wise policy to introduce a similar non-native species.

☐ A. True

☐ B. False

9. The period of modern man is one of the greatest periods of mass species extinctions the planet has ever seen.

☐ A. True

☐ B. False

10. Natural changes cause stress to some plants and animals while benefiting others.

☐ A. True

☐ B. False

11. Urbanization can cause stream channels to become wider and deeper.

☐ A. True

☐ B. False

12. With the absence of human intervention, a totally natural disturbance to an ecosystem will eventually result in the same ecosystem after a full recovery.

☐ A. True

☐ B. False

13. Most suspended sediment in streams and rivers comes from the erosion of streambanks rather than from overland flow across croplands.

☐ A. True

☐ B. False

14. A watershed with 25% impervious surface is likely to have increased runoff and higher peak streamflows, but probably no other problems.

☐ A. True

☐ B. False

15. A large percentage of irrigation water withdrawn from rivers and streams never makes it to the point of watering the crops due to inefficient water handling.

☐ A. True

☐ B. False

16. An urban watershed with 25% impervious surface will probably experience 100-year flood levels once every five years, on average.

☐ A. True

☐ B. False

17. Fire is an important, beneficial agent of change to western deciduous forest species.

☐ A. True

☐ B. False

18. Dynamic equilibrium implies that a watershed can undergo changes in physical form or biological communities, and still maintain stability and function as long as the changes occur within a normal range of magnitude and frequency.

☐ A. True

☐ B. False

19. Buffer strips along streambanks are part of the remedy for most of the water quality problems that arise from agriculture and timber harvest.

☐ A. True

☐ B. False

20. Agriculture represents the heaviest demand for water in most parts of the United States, and accounts for more than 2/3 of global water use.

☐ A. True

☐ B. False

ANSWERS

Q1: C Q2: E Q3: H Q4: C Q5: E Q6: A Q7: B Q8: B
Q9: A Q10: A Q11: A Q12: B Q13: B Q14: B Q15: A Q16: A
Q17: B Q18: A Q19: A Q20: A

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ENERGY/ENVIRONMENT

Clean Water Act at 40: Is it failing to meet new pollution challenges?

Congress passed the far-reaching Clean Water Act 40 years ago. The measure scored dramatic environmental successes, including with Lake Erie. But now Erie, and the law, are besieged.

By Richard Mertens, Correspondent | OCTOBER 18, 2012

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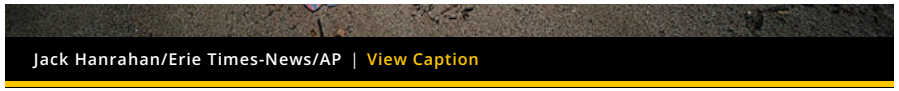

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CHICAGO — When Rick Unger was a boy, he and his father would fish from the breakwall where the Cuyahoga River enters Lake Erie.

“I remember the smell,” says Mr. Unger, now 59. “I remember the oil slicks. I remember the fishing not being very good.”

The Cuyahoga was then so polluted that the surface occasionally caught fire. Erie was considered a “dead” lake; in summer floating mats of stinking blue-green algae consumed so much oxygen in the water that large areas of the lake were rendered lifeless.

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But in 1972 Congress passed the Clean Water Act, one of the most far-reaching and ambitious environmental laws ever enacted in the United States. The act cut industrial pollution, set new goals for the health of the nation’s waters, and provided billions of dollars to help cities build and upgrade sewage treatment plants.

The effect on the Cuyahoga and Lake Erie was swift and dramatic. Within years, the algae blooms disappeared. The Cuyahoga stopped burning. Fishing improved.

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“We had a terrific lake again,” says Unger, now a charter boat captain and president of the Lake Erie Charter Boat Association. Lake Erie became known as the “Walleye Capital of the World.”

Now, 40 years later, Lake Erie is once more in trouble. In recent summers large blooms of toxic algae have returned. In 2011, the worst year so far, there were days when the algae was so thick that Unger couldn’t take his customers fishing. He once drove his 27-foot Sportcraft boat 14 miles straight north from Cleveland before he gave up and turned back. “I never got out of the algae,” he says.

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The recovery and decline of the Lake Erie ecosystem offer a vivid illustration of both the successes and failures of the Clean Water Act in cleaning up and protecting the nation’s waters.

Experts on environmental history and policy say that, since the act, much progress has been made: cleaning up rivers and lakes, protecting estuaries and wetlands, and curbing pollution from industry and municipal sewage – problems that were acute by the 1970s despite earlier efforts to stop pollution.

The Environmental Protection Agency (EPA) estimates that in 1972 two-thirds of the waters in America were unfit for fishing or swimming. Today, it says, that amount has been cut in half, to one-third.

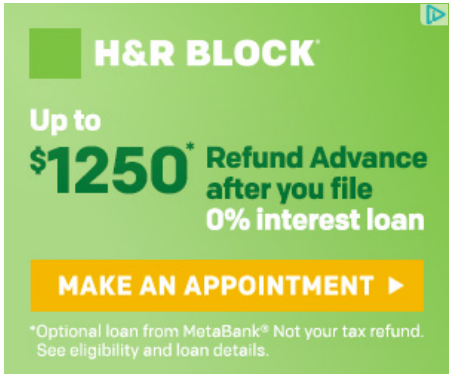
At the same time, shortcomings in the Clean Water Act and its implementation have left the nation with problems that are being addressed too slowly or hardly at all, experts and environmental advocates say. Here's a synopsis of some of these problems.

• Runoff from urban areas carries pollutants from streets and lawns into lakes and rivers. During storms, this runoff can overwhelm sewer systems, sending untreated sewage into nearby waters. Many cities are working to separate sewers that carry rainwater from those that carry sewage. Some, like Philadelphia, Milwaukee, and Washington, D.C., are also promoting the use of "green infrastructure" to reduce runoff.

• Pollution standards for different industries – standards that determine what the industries can put into the water and what they can't – are out of date. Plus, new pollutants are emerging, including pharmaceuticals and cosmetics.

"People are inventing new chemicals faster than we can figure out what to do about them," says William Hines, a professor of law at the University of Iowa in Iowa City.

• Aging infrastructure – including treatment plants and sewage systems that in some cities date to the 19th century – is a growing threat to water quality. Even sewage treatment plants built with federal money in the early



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years of the Clean Water Act are in need of upgrades.

“If we don’t reinvest in that infrastructure, we’ll start falling backwards again, in part due to population growth,” says Robert Adler, a professor of law at the University of Utah in Salt Lake City and the author of a book on the Clean Water Act.

• The act left largely untouched the leading cause of pollution today, known as “nonpoint” pollution. The largest source of this is runoff from agriculture. Each year, for example, fertilizer from Midwestern cornfields washes down the Mississippi River and creates a “dead zone” in the Gulf of Mexico. Farm runoff is an ongoing problem in many smaller bodies of water, including Chesapeake Bay, Lake Erie, and many other lakes and rivers around the country. Under the Clean Water Act, states have been identifying thousands of bodies of water polluted by excess nutrients from agriculture. But the act gives the federal government little power to regulate agricultural pollution. “We keep talking about plans, but there’s very little execution,” says Mr. Hines.

The Clean Water Act was one of a trio of sweeping environmental laws enacted in the early 1970s, including the Clean Air Act (1970) and the National Environmental Policy Act (1970). It came at a time of growing interest in the environment and of readiness to extend the powers of the federal government.

Environmental regulation in the United States dates to the 19th century. But the Clean Water Act was different in that it greatly expanded federal powers to curb pollution, a job previously left to the states. By allowing

private citizens to bring lawsuits over pollution, the Clean Water Act also opened up new opportunities for citizen action.

For example, Heal the Bay, an environmental group in Los Angeles, got started when a group of citizens invoked the Clean Water Act in a fight to clean up Santa Monica Bay. “We’ve been working the Clean Water Act ever since,” says Kirsten James, the organization’s water quality director.

In part, the Clean Water Act was a victim of its own overarching ambitions. It set standards that turned out to be impossible for the country to meet. The act said that by 1983, all waters should be clean enough for fishing and recreation. By 1985, it said, the discharge of all pollution should be stopped.

“It struck me at the time that it just wasn’t realistic,” says Hines, a critic of the act when it was enacted. Today, he says, “I feel kind of sad that we’re not further down the road.”

After four decades, much remains to be done. According to a recent EPA survey, 54 percent of the nation’s river miles, 69 percent of its lakes and reservoirs, 66 percent of its estuaries, and 85 percent of its wetlands are in some way impaired.

Of course the Clean Water Act didn’t just set goals; it came with large sums of money to reach them. From 1970 to 1995, the federal government spent $61 billion to help cities upgrade and build sewage treatment plants. This sharply reduced the amount of organic pollutants, especially nitrogen and phosphates, that were overloading the nation’s waters.

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But federal largess has dwindled. By 1987, the assistance had shifted to a $16 billion revolving loan fund. Mr. Adler says as much as a trillion dollars may be needed over the next 20 years. “The remaining capital needs … are staggering,” he says.

Lake Erie was one of the leading beneficiaries of the Clean Water Act. Its restoration was the “best example of ecosystem recovery in the world,” says Jeffrey Reutter, a biologist at Ohio State University. The main reason was that improved sewage treatment around the lake reduced the amount of phosphorus, an important nutrient for algae, getting into the water.

Since the mid-1990s, however, the amount of phosphorus has begun to rise again. Some still comes from municipal sewage plants, but the chief culprit is farming.

Steve Davis, a watershed specialist for the Natural Resources Conservation Service in Lima, Ohio, says farmers have in many ways improved their practices. Many no longer plow their land but use “no till” methods. At the same time, they have taken to applying fertilizer in the winter, when it is more likely to wash off the fields.

Mr. Davis encourages farmers to adopt conservation methods such as using cover crops in winter, planting buffer strips along creeks and other waterways, testing soils to determine how much fertilizer their fields really need – and refraining from applying fertilizer in winter. Federal grants offer incentives.

“It’s a big challenge and a complicated problem, but a lot of people are working on it,” he says.

Unger and his fellow charter captains do their part by taking farmers out on Lake Erie to show them what farming is doing to the lake.

One farmer gazed upon the pea-green water and told him, “I don’t know whether to kiss you or hate you. I’m not going to be able to apply fertilizer without thinking of what you stand to lose.”

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Administration finalizes repeal of 2015 water rule Trump called ‘destructive and horrible’

Eilperin, Juliet; Dennis, Brady . The Washington Post (Online) , Washington, D.C.: WP Company LLC d/b/a The Washington Post. Sep 11, 2019.

ProQuest document link

FULL TEXT

For years, the fight over how much power the federal government should have to regulate the wetlands and tributaries that feed into the nation's largest rivers has played out across the country.

In the halls of Washington and on sprawling farms and ranches, in courtrooms and corporate boardrooms, a legal tug of war has unfolded over a 2015 rule that gave the Environmental Protection Agency much broader authority over the nation's waterways. Critics say the Obama-era rule gave the federal government far too much power; supporters countered it would prevent the loss of vast swaths of wetlands. Court rulings have temporarily blocked the regulation in 28 states, while keeping it in effect in 22 others.

On Thursday, the Trump administration plans to scrap the Obama-era definition of what qualifies as "waters of the United States" under the Clean Water Act, returning the country to standards put in place in 1986.

"What we have today is a patchwork across the country," EPA Administrator Andrew Wheeler said in an interview. "We need to have a uniform regulatory approach."

Wheeler, who said the administration will finalize a new definition for which water bodies deserve federal protection within a matter of months, said the agency is seeking to end any lingering uncertainty and return more oversight to individual states.

"We want to make sure that we have a definition that once and for all will be the law of the land in all 50 states," Wheeler said.

Critics say the rollback will speed the conversion of wetlands and headwaters, which provide critical habitat for wildlife and support the nation's drinking-water supply. Americans drained about half of the 220 million acres of wetlands in the contiguous United States between the 1780s and 1980s, most of it to expand farmland. That rate began to slow in the 1980s, and after George H.W. Bush took office he pledged to stem the tide of wetlands loss.

"The administration wants to go back to an era where we are destroying wetlands heedlessly," Robert Irvin, president of the American Rivers organization, said of President Trump's latest deregulatory effort.

The 2015 rule gave the federal government authority to oversee a wide array of lakes, streams, wetlands, storm-water controls and ditches feeding into larger waterways that are clearly protected under the 1972 Clean Water Act.

Denise Stranko, federal legislative and policy manager for the Chesapeake Bay Foundation, noted that all but one of the six states in the bay's watershed, along with the District of Columbia, operate under the Obama-era standard. She added that once the administration finalizes its substitute proposal, tens of thousands of acres that connect underground or through ditches to nearby waterways will lose protection.

Targeting the Obama-era regulation ranked among Trump's top priorities when he took office. In February 2017, he issued an executive order directing the EPA to review the regulation in an effort to pave the way for what Trump called "the elimination of this very destructive and horrible rule."

The Clean Water Act makes it unlawful to pollute a "water of the United States" without a permit, but what constitutes such water has been the subject of lengthy litigation.

In a 2006 decision, *Rapanos v. United States*, the Supreme Court's four most conservative justices at the time offered a constrained view that only "navigable waters" met this test. But Justice Anthony M. Kennedy, who refused to join the conservatives or the liberals on the court, said that the government could intervene when there was a "significant nexus" between large water bodies and smaller ones.

Trump's executive order said federal officials should rely on the opinion of the then-Justice Antonin Scalia, who argued that the law should apply to wetlands connected to "relatively permanent" bodies of water as well as navigable waters.

Wheeler is slated to announce the final repeal of the 2015 rule at the National Association of Manufacturers, whose members had pushed to scale it back. "America is now one step closer to smart and balanced regulation that protects our nation's precious water resources," the group's president, Jay Timmons, said in a statement.

Thursday's move is part of a broader effort by the administration to roll back regulations affecting the private sector before the end of Trump's first term. Among the dozens already reversed are rules on everything from curbing methane emissions from drilling operations to holding oil and gas companies responsible for killing birds that get ensnared in their rigs' waste pits.

"We will finalize all of our top priorities," Wheeler said.

Several of the administration's early wins came through the Congressional Review Act, which allows lawmakers to nullify any rule within 60 days of enactment. The Republican-controlled Congress in 2017 was able to overturn several of President Barack Obama's last environmental acts that way, sending the bills to Trump for his signature.

Reversing older regulations, such as the Clean Water Rule, has proved more difficult. Wheeler said it was taking longer than first anticipated to finalize the administration's new standards because staffers were conducting economic and scientific research to bolster the case for shrinking the federal government's authority over wetlands and streams.

"I'm not in a rush to meet artificial deadlines," he said. "I want to make sure that our regulations are grounded, that they have all the supporting information they need to be upheld by the courts."

Irvin said his group was prepared to take the EPA to court over its latest rollback.

"Clearly the administration is intent on rolling back as many protections as it can before January of 2021," he said. "Like any rushed efforts, they are likely to make mistakes that will be challenged and overturned in court."

Supporters of the administration are eager for the change.

On a recent evening in Hugo, Minn., Fran Miron looked out over the 800-acre farm that his family has maintained for four generations and explained why he welcomes the Trump administration's latest rollback. He said the Obama rule led to widespread confusion, as well as worries about increasing costs and red tape.

"In my opinion, and I think it's shared by many, this was really just a power grab," said Miron, 65, whose family milks 120 cows and grows corn, soybeans and alfalfa.

A former mayor of Hugo, Miron said he believes that the federal government doesn't always know what's best for a particular place.

"The best decisions are made locally because the local people understand the nature of the issues," he said. "They understand the nuances of the land and our water."

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DETAILS

Subject:	Regulation; Creeks &streams; Federal government; Presidents; Executive orders; Wetlands
Location:	Chesapeake Bay United States--US Washington DC

People:	Trump, Donald J Kennedy, Anthony M Wheeler, Andrew Bush, George Scalia, Antonin Obama, Barack
Company / organization:	Name: American Rivers; NAICS: 813410, 813940; Name: National Association of Manufacturers; NAICS: 813910; Name: Congress; NAICS: 921120; Name: Environmental Protection Agency--EPA; NAICS: 924110; Name: Chesapeake Bay Foundation; NAICS: 813211
Publication title:	The Washington Post (Online); Washington, D.C.
Publication year:	2019
Publication date:	Sep 11, 2019
Section:	Climate-environment
Publisher:	WP Company LLC d/b/a The Washington Post
Place of publication:	Washington, D.C.
Country of publication:	United States, Washington, D.C.
Publication subject:	General Interest Periodicals--United States
ISSN:	26419599
Source type:	Blogs, Podcasts, &Websites
Language of publication:	English
Document type:	News
ProQuest document ID:	2289229630
Document URL:	https://search.proquest.com/docview/2289229630?accountid=14512
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Last updated:	2019-09-13
Database:	The Washington Post

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